From range of motion to function

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From range of motion to function

Loss of joint flexibility after burns: when is it a problem?

Anouk Oosterwijk

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General introduction

GENERAL INTRODUCTION

Flexibility is defined as the range of motion (ROM) available at a joint.[1] To perform daily activities, a sufficient ROM in each specific movement direction of all joints is required. Unfortunately, many patients suffer from loss of ROM as a primary or secondary condition of various diseases, disorders and ageing.[2,3] The cause of such ROM loss can lie in shortening of various types of tissue, such as muscles, tendons, ligaments, or the skin.[4] Shortening of skin tissue is a well-known long-term complication after burn injury, due to excessive scarring and ongoing scar contraction.[5,6] In these cases, ROM loss is called a scar contracture. Scar contractures can threaten functioning, including the performance of daily tasks and participation in the society. On this basis health-related quality of life can also be affected.[7-10] However, contractures can vary from only a few degrees to many degrees loss of ROM and it is unknown when a contracture actually leads to problems in functioning. To get insight into the extent of the problem, an important question to answer is therefore: when is a certain degree of ROM loss actually a problem for the patient? This thesis focusses on the relation between the loss of ROM due to scar contractures after burn injuries and the performance of daily tasks.

Burns

Worldwide, millions of people suffer from burns and burn related disabilities and disfigurements.[11] In earlier days, the mortality rate as a result of burn injuries was high. Because of major improvements in burn treatment and care during the past decades, the survival rate of burn patients has increased enormously, specifically in the developed world, even if these patients have severe burns.[12-13]

The severity of a burn depends on the extent of the body surface area that is burned and the depth of the burn. The extent of a burn is expressed as the percentage of the total body surface area (%TBSA) burned. To give you an idea, the patient's hand palm, including the fingers, is roughly equivalent to 1% of that person's body surface area.[14,15] The depth of a burn can be divided into superficial, partial-thickness and full-thickness (Figure 1).[16] In superficial burns, sometimes called first degree burns, only the epidermis is affected. Its characteristics are pain, redness and mild swelling. Superficial burns are not included in determining the extent of a burn and heal spontaneously without treatment. In partial-thickness burns, or second-degree burns, the dermis, or parts of it, is destroyed. Characteristics of partial thickness burns are pain, moist, splotchy, swelling and blisters. This type of burn can further be divided in superficial partial-thickness and deep partial-thickness burns. Superficial partial-thickness burns heal spontaneously without scars because of the presence of epithelial elements. Deep partial-thickness burns will mostly require skin grafting. In full-thickness burns, or third degree burns, all layers of the skin are destroyed and the damage may even penetrate the layer of subcutaneous fat. Unlike other burn types, a full-thickness burn is painless when touched because the nerve endings responsible for sensation are destroyed. The burned area can appear white, grey or black, dry and leathery. Treatment for this type of burn usually requires skin grafting to close the wound.[17,18]

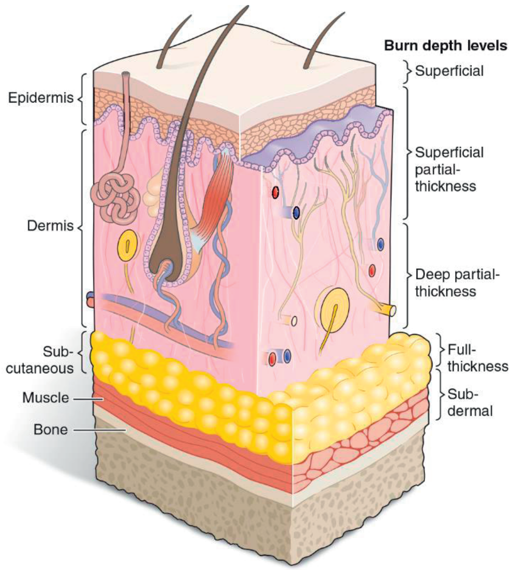

Figure 1 - Histological presentation of depth of burn.

Time till wound healing depends on both the extent and depth of the burn as well as on personal factors such as age, comorbidity, and complications.[19,20] In general, superficial partial-thickness burns heal within two to three weeks after injury whereas wound healing of deep partial- and full-thickness burns takes longer than three weeks.[21] During the wound healing phase, pain, edema and avoidance behavior can result in a loss of flexibility of the joints involved in a burn injury.[22,23]

After wound healing, a well-known complication is the development of burn scar contractures, defined as the pathological outcome of excessive scarring and ongoing scar contraction of myofibroblasts, sometimes over several years.[6,18] This contracting scar tissue brings discomfort and can limit the flexibility of joints on the long-term.[24] Scar contractures mainly occur after deep partial- and full-thickness burns, in patients with a higher percentage of TBSA burned, and after flame burns. Furthermore, joints of the upper extremity seem to be more affected by scar contractures than those of the lower extremity.[5, 25-27]

Considerable clinical and research effort has gone into the prevention and treatment of burn scar contractures. Prevention and treatment of scar contractures includes positioning, splinting, exercise, pressure garments, and surgical correction.[27-33] Despite all efforts, scar contractures still occur even with these standard methods of care.[22,23] Insight in the prevalence, the course, and the severity of scar contractures is essential to be able to evaluate current treatment and care and to direct development of new treatment strategies to prevent and/or correct burn scar contractures. Thereby the primary interest goes to the scar contractures that cause loss of joint ROM that actually impacts a patient's functioning.

Relation between ROM loss and patient's functioning

To gain insight into the extent of the problem of the construct 'contracture', this construct has to be converted into measurable characteristics, also called an operationalization. So far, treatment goals to maintain or restore full ROM of joints are usually established in terms of norm ROM, i.e., the maximal ROM of a specific joint in a particular movement direction in unimpaired subjects during active movement. For example, the norm ROM for shoulder abduction is 180 degrees, whereas for elbow extension this is 0 degrees and for knee flexion 135 degrees.[34,35] Loss of ROM is than defined as the difference in degrees between the measured ROM that the patient is able to perform actively with the impaired joint in a specific movement direction and the corresponding norm ROM. Although the number of degrees ROM loss provides clinicians and therapists with valuable information, the question arises if restoring to norm ROM has to be the primary treatment goal. For example, some healthy people have a natural hyperextension of the elbow, up to -10 degrees, while others cannot fully straighten their elbow to 0 degrees and therefore cannot achieve norm ROM. For this last group as well as for the group of people with scar contractures after burn injury, a measured ROM of some degrees below norm ROM may not be a problem for functioning. Another example is a patient with a burn scar over the shoulder joint limiting shoulder abduction motion to 174 degrees who may not be able to raise his arm as far as the norm ROM for unimpaired individuals (180 degrees). Does this loss of motion really threatens functioning? If yes, how severe is the problem? If not, where is the critical point at which a certain loss of ROM hampers patient's performance on one or more activities of daily living (ADL)? For instance, when can hair not be combed naturally anymore so that compensatory movements are performed or that additional tools are needed? The important question thus is: 'when is a certain degree of ROM loss actually a problem?' In clinical practice this question is often answered in terms of 'the critical joint angles when ROM loss threatens functioning'. But what is meant by functioning and at which joint angles is functioning threatened?

In the International Classification of Functioning, Disability and Health (ICF) model of the World Health Organization[36] the term 'functioning' refers to the dynamic interaction between *body functions and structures, activities* and *participation*, in which person's health conditions, environmental factors, and personal factors play an important role (Figure 2). Following this, 'disability' is described in the terms of *impairments, activity limitations* and *participation restrictions.* To answer the question 'when is a certain degree of ROM loss actually a problem', an important step then is to relate flexibility of joints (*body function and structure*) and daily activities (*activities*), or, in terms of 'disability' in people with burns, clarity the relation between ROM loss due to scar contractures (*impairment*) and limitations in the performance of daily tasks (*activity limitations*) (Figure 2).

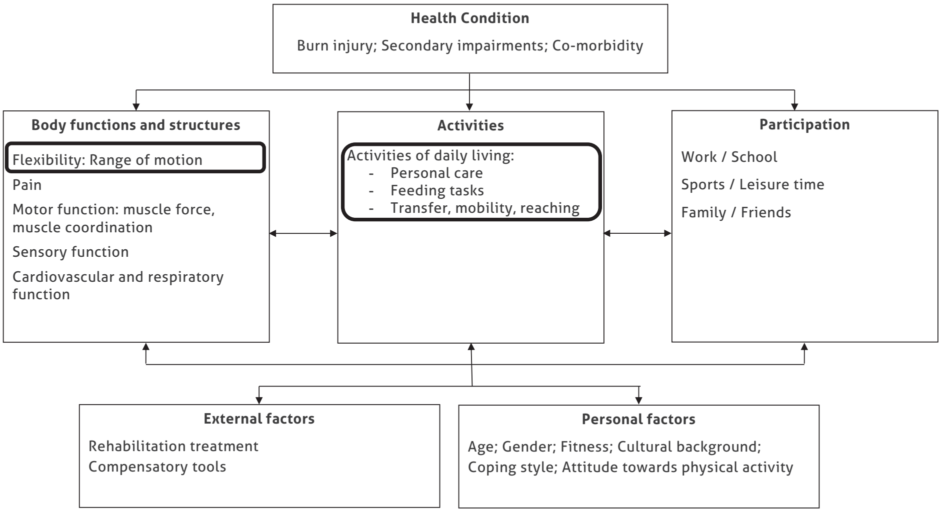

Figure 2 - Relating ROM loss to limitations in the performance of daily activities in the ICF model.

In clinical practice, the most common and usual way to gather information concerning ROM related limitations in functioning is of course asking the patient about their experiences. Answers on such questions provide clinicians with valuable information on self-perceived functioning. However, this information is not readily applicable for research purposes on ROM related problems of the whole patient population.

Besides asking the patient, information concerning ROM related limitations in functioning is also often gathered by questionnaires and/or scoring patient's performance on a small set of ADL tasks. Questionnaires used in this context are for example the Patient Specific Functional Scale (PSFS)[37] or the Disabilities of Arm, Shoulder and Hand (DASH).[38] These questionnaires are patient-reported outcome measures, designed to assess perceived functional performance change over time. Scoring is done on ordinal Likert Scales ranging from 'unable to perform' to 'able to perform at prior level / no difficulty' by the patient. To ascertain actual independent functional performance of a patient, scoring the performance on a small set of ADL tasks is done by an observer. Examples of scoring current levels of (dis)ability associated with relevant activities are for instance (a large part of) the Barthel Index (BI)[39] or the Frenchay Arm Test (FAT).[40]

The advantage of scoring with a questionnaire or scoring on a small set of ADL tasks is that it quickly gives an idea of respectively the perceived ability to perform or actual independent performance of daily functioning, although perceived ability to perform and actual performance may differ. The disadvantage of scoring with a questionnaire or scoring on a small set of ADL tasks is that perceived ability to perform and actual performance are also influenced by other factors than ROM loss, such like pain, loss of muscle force, loss of muscle coordination or loss of sensibility. Another factor that is neglected in these methods is that ADL tasks can be accomplished with substantial ROM loss in a specific joint by performing adequate compensatory movements in other components of the coordinated joint system. This means that joint flexibility might be rated as unproblematic, while such compensatory movements have become part of daily functioning, which on the long-term is likely to lead to secondary conditions due to overuse.[41-43] Therefore, limitations in functioning due to specific ROM loss are difficult to determine with these methods and possible long-term problems are neglected.

Rating scales that are used in physiotherapy as well as in the field of burn injuries and orthopedics can also derive information concerning the severity of limitations in functioning due to contractures. These rating scales classify degrees of ROM loss into different severity categories, for example 'mild', 'moderate' or 'severe'. Specific for burns, recent examples of such rating scales are the Burn Scar Contracture-Severity Scale (BCS-SS)[44] and Schneider's burn contracture scale.[5] In other scales, the ROM loss scores are sometimes combined with scores on other factors such like pain, muscle force and perceived or actual disability during performance of daily tasks, to yield a summarized score. Examples of such summarized scores are the Constant Score[45,46] and the Liverpool Elbow Score.[47] However, for all rating scales, it is unknown how loss of ROM expressed in the different severity levels is related to limitations in performance of activities and/or restrictions in participation without compensatory movements.

To summarize, a lot of methods are available to gather information concerning loss of joint flexibility. As the relevance of joint flexibility is function, the question is whether the outcomes reflect function.

AIMS AND OUTLINE OF THIS THESIS

The aim of this thesis is to challenge current methods used to evaluate the presence and severity of scar contractures and make a start with the operationalization of the construct 'contracture' in terms of functional outcomes in daily life.

The purpose of **CHAPTER 2** is bringing together current knowledge about the presence of scar contractures over the last decades in people with burns in a systematic review. To evaluate the extent of the problem of joint contractures in terms of function and to establish function-related treatment goals, it is necessary to determine the joint angles that are required to perform daily tasks, in this thesis subsequently called functional ROMs. In **CHAPTER 3**, the functional ROMs for the different shoulder and elbow movement directions are determined by compiling and synthesizing joint angles used by unimpaired individuals when accomplishing daily activities. These functional ROMs of the shoulder and elbow are then used to determine whether current severity levels of rating scales of ROM impairment in burn research as well as in orthopedics and physiotherapy are related to function in **CHAPTER 4**. The aim of the study in **CHAPTER 5** is to compare the generally used norm ROM-method and its derivatives with the functional ROM-method and patient-reported functional outcomes of a questionnaire, with the use of actual burn data. In **CHAPTER 6**, the functional ROMs are used to describe the course of prevalence of scar contractures limiting daily function in children and adolescents over the initial six months after burn.

REFERENCES

1. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep 1985;100:126-131.
2. Fergusson D, Hutton B, Drodge A. The epidemiology of major joint contractures: a systematic review of the literature. Clin Orthop Relat Res 2007;456:22-9.
3. Offenbächer M, Sauer S, Rieß J, Müller M, Grill E, Daubner A, et al. Contractures with special reference in elderly: definition and risk factorsÐa systematic review with practical implications. Disabil Rehabil 2014;36:529-38.
4. Youngson RM. Collins dictionary of medicine. 4th ed. Glasgow: HarperCollins; 2005.
5. Schneider JC, Holavanahalli R, Helm P, Goldstein R, Kowalske K. Contractures in burn injury: defining the problem. J Burn Care Res. 2006;27:508-14.
6. Schouten HJ, Nieuwenhuis MK, van Zuijlen PP. A review on static splinting therapy to prevent burn scar contracture: do clinical and experimental data warrant its clinical application? Burns 2012;38:19-25.
7. Palmieri TL, Petuskey K, Bagley A, Takashiba S, Greenhalgh DG, Rab GT. Alterations in functional movement after axillary burn scar contracture: a motion analysis study. J Burn Care Rehabil 2003;24:104-8.
8. Leblebici B, Adam M, Bagis S, Tarim AM, Noyan T, Akman MN, et al. Quality of life after burn injury: the impact of joint contracture. J Burn Care Res 2006;27:864-8.
9. Fischer U, Müller M, Strobl R, Bartoszek G, Meyer G, Grill E. Examining functioning and contextual factors in individuals with joint contractures from the health professional perspective using the ICF: an international internet-based qualitative expert survey. Rehabil Nurs 2016;41:170-8.
10. Heise M, Müller M, Fischer U, Grill E. Quality of life in older individuals with joint contractures in geriatric care settings. Qual Life Res 2016;25:2269-81.
11. World Health Organization. WHO fact sheet on burns. 2018. Last assessed 1 October 2019 from https://www.who.int/news-room/fact-sheets/detail/burns
12. Brusselaers N, Hoste EA, Monstrey S, Colpaert KE, de Waele JJ, Vandewoude KH, Bolt SI. Outcome and changes over time in survival following severe burns from 1985 to 2004. Intensive Care Med 2005;31:1648-53.
13. Strassle PD, Williams FN, Napravnik S, van Duin D, Weber DJ, Charles A, Cairns BA, Jones SW. Improved survival of patients with extensive burns: trends in patient characteristics and mortality among burn patients in tertiary care burn facility, 2004-2013. J Burn Care Res 2017;38:187-93.
14. Sheridan RL, Petras L, Basha G, Salvo P, Cifrino C, Hinson M, et al. Planimetry study of the percent of body surface represented by the hand and palm: sizing irregular burns is more accurately done with the palm. J Burn Care Rehabil 1995;16:605-6.
15. Nagel TR, Schrunk JE. Using the hand to estimate the surface area of a burn in children. Pediat Emerg Care 1997;13:254-5.
16. Figure 1 from: SH Roy, SL Wolf, DA Scalzitti. The Rehabilitation Specialist's Handbook. Section VII: Integumentary. 4th ed. F.A. Davis Company; 2013. https://fadavispt.mhmedical.com/content.aspx?bookid=1901&sectionid=137478239
17. Heimbach D, Engrav L, Grube B, Marvin J. Burn depth: a review. World J Surg 1992;16:10-5.

18. Hawkins HK, Jay J, Finnerty CC. Pathophysiology of the burn scar. In: Herndon DN, editor. Total Burn Care. 5th ed. Edinburgh: Elsevier Inc.; 2018. p. 466-75.
19. Guo S, DiPietro LA. Factors affecting wound healing. J Dent Res 2010;89:219-29.
20. Rowan MP, Cancio LC, Elster EA, Burmeister DM, Rose LF, Natesan S, Chan RK, Christy RJ, Chung KK. Burn wound healing and treatment: a review and advancements. Crit Care 2015;19:243.
21. Schouten HJ, Bouwmeester K, van der Hoeven W, Arends R, Dumans A, van der Linden D. Handboek fysiotherapie en ergotherapie bij brandwonden. 1st ed. Beverwijk: Nederlandse Brandwonden Stichting; 2005:13-5.
22. Goverman J, Mathews K, Goldstein R, Holavanahalli R, Kowalske K, Esselman P, et al. Adult contractures in burn injury: a burn model system national database study. J Burn Care Res 2017;38:e328-36.
23. Schouten HJ, Nieuwenhuis MK, van Baar ME, van der Schans CP, Niemeijer AS, van Zuijlen PPM. The prevalence and development of burn scar contractures: a prospective multicenter cohort study. Burns 2019;45:783-90.
24. Falder S, Brouwne A, Edgar D, Staples E, Fong J, Rea S, Wood F. Core outcomes for adult burn survivors: a clinical overview. Burns 2009;35:618-41.
25. Kowalske K, Holavanahalli R, Sergio M, Esselman P, Ware L, Delateur B, et al. Contractures following burn injury in children and adults. J Burn Care Res 2003;24:S85.
26. Gangemi EN, Gregori D, Berchialla P, Zingarelli E, Cairo M, Bollero D, et al. Epidemiology and risk factors for pathologic scarring after burn wounds. Arch Facial Plast Surg 2008;10:93-102.
27. Hop MJ, Langenberg LC, Hiddingh J, Stekelenburg CM, van der Wal MB, Hoogewerf CJ, et al. Reconstructive surgery after burns: a 10-year follow-up study. Burns 2014;40:1544-51.
28. Richard R, Miller S, Staley M, Johnson RM. Multimodal versus progressive treatment techniques to correct burn scar contractures. J Burn Care Rehabil 2000;21:506-12.
29. Dewey WS, Richard RL, Parry IS. Positioning, splinting, and contracture management. Phys Med Rehabil Clin N Am 2011;22:229-47.
30. Kolmus AM, Holland AE, Byrne MJ, Cleland HJ. The effects of splinting on shoulder function in adult burns. Burns 2012;38:638-44.
31. Lester ME, Hazelton J, Dewey WS, Casey JC, Richard R. Influence of upper extremity positioning on pain, paresthesia, and tolerance: advancing current practice. J Burn Care Res 2013;34:e342-50.
32. Godleski M, Oeffling A, Bruflat AK, Craig E, Weitzenkamp D, Lindberg G. Treating burn-associated joint contracture: results of an inpatient rehabilitation stretching protocol. J Burn Care Res 2013;34:420-6.
33. Lee JO, Herndon DN, Andersen C, Suman OE, Huang TT. Effect of exercise training on the frequency of contracture-release surgeries in burned children. Ann Plast Surg 2017;79:346-9.
34. American Academy of Orthopaedic Surgeons: Joint Motion: Methods of Measuring and Recording. AAOS, Chicago, 1965.
35. Magee DJ. Orthopedic physical assessment. 5th ed St Louis: Saunders Elsevier; 2008.
36. World Health Organization. International Classification of Functioning, Disability and Health (ICF). 2001.
37. Stratford P, Gill C, Westaway M, Binkley J. Assessing Disability and Change on Individual Patients: A Report of a Patient Specific Measure. Physiother Can 1995;47:258-63.
38. Hudak PL, Amadio PC, Bombardier C, Upper Extremity Collaborative Group

(UECG). Development of an upper extremity outcome measure: the DASH (disabilities of the arm, shoulder and hand) [corrected]. Am J Ind Med 1996;29:602-8.
39. Mahoney FI, Barthel DW. Functional evaluation: the Barthel Index. Md State Med J 1965;14:61-5.
40. Heller A, Wade DT, Wood VA, Sunderland A, Hewer RL, Ward E. Arm function after stroke: measurement and recovery over the first three months. J Neurol Neurosurg Psychiatry 1987;50:714-9.
41. Mell AG, Childress BL, Hughes RE. The effect of wearing a wrist splint on shoulder kinematics during object manipulation. Arch Phys Med Rehabil 2005;86:1661-4.
42. Veeger HE, Magermans DJ, Nagels J, Chadwick EK, van der Helm FC. A kinematical analysis of the shoulder after arthroplasty during a hair combing task. Clin Biomech 2006;21:S39-44.
43. de Groot JH, Angulo SM, Meskers CG, van der Heijden-Maessen HC, Arendzen JH. Reduced elbow mobility affects the flexion or extension domain in activities of daily living. Clin Biomech 2011;26:713-7.
44. Niedzielski LS, Chapman MT. Changes in burn scar contracture: utilization of a severity scale and predictor of return to duty for service members. J Burn Care Res 2015;36:e212-9.
45. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res 1987;214:160-4.
46. Constant CR, Gerber C, Emery RJ, Søjbjerg JO, Gohlke F, Boileau P. A review of the Constant score: modifications and guidelines for its use. J Shoulder Elbow Surg 2008;17:355-61.
47. Sathyamoorthy P, Kemp GJ, Rawal A, Rayner V, Frostick SP. Development and validation of an elbow score. Rheumatology (Oxford). 2004;43:1434-40.

2

Prevalence of scar contractures after burn: a systematic review

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ABSTRACT

Objective: Burn scar contractures are the pathological outcome of excessive scarring and ongoing scar contraction. Impairment of joint range of motion is a threat to performing activities in daily living. To direct treatment strategies to prevent and/or correct such contractures, insight into the prevalence, course, and determinants is essential.

Methods: A literature search was conducted including Pubmed, Cochrane library, CINAHL, and PEDro. Articles were included if they provided burn scar contracture data to calculate the point prevalence. The quality of the articles was scored. Data were extracted regarding study, subject and burn characteristics, method of scar contracture assessment, point prevalence, and possible determinants.

Results: Nine articles and one abstract could be included for data extraction. The prevalence at discharge was 38-54%, but with a longer time after burn, the prevalence was lower. Contractures were more likely to occur in more severe burns, flame burns, children, female, the cervical spine, and the upper extremity.

Conclusions: The prevalence of burn scar contractures varies considerably between studies. When prevalence is unclear, it is also difficult to investigate potential determinants and evaluate changes in interventions. There is a need for extensive, well-designed longitudinal (inter)national studies that investigate prevalence of scar contractures, their evolvement over time, and risk factors.

INTRODUCTION

Scar contractures are the pathological outcome of excessive scarring and ongoing scar contraction and a well-known complication after burns.[1-3] Scar contractures impair the range of motion (ROM) of joints and thus may limit performing activities of daily living.[4,5] When daily activities cannot be performed optimally, both actual and perceived physical health can be affected and a person's health-related quality of life is threatened.[2,5] Furthermore, there is a risk of secondary conditions, for example, due to overuse of adjacent and/or unaffected joints.

Considerable clinical and research effort has gone into the prevention and treatment of scar contractures including positioning, splinting, exercise, and surgical correction.[6-12] Additionally, specific patient and/or burn related factors may influence the occurrence of scar contractures. Despite all effort, it is well known that scar contractures after burn still occur with the usual methods of care.[1,12-16] To be able to evaluate current care and to direct development of new treatment strategies to prevent and/or correct scar contractures, in our opinion, insight in the prevalence, course and determinants of scar contractures is essential. The aim of this study therefore was to determine the prevalence of scar contractures in patients after burn with attention to possible determinants.

METHODS

For reporting, the Preferred Reporting Item for Systematic Reviews and Meta-Analysis (PRISMA) was applied.

Data sources and search strategy

A literature search was conducted making use of electronic databases, checking the reference lists of retrieved relevant articles and reviews, personal knowledge, and serendipitous discovery. The electronic databases that were searched included Pubmed, Cochrane library, CINAHL, and PEDro. Combinations of (variations of) the following keywords and free text were included: burns; thermal injury; contracture; range of motion; incidence; prevalence; and epidemiology. The search was unrestricted in language or publication status but was limited to studies concerning human subjects. The final search was completed in November 2014.

Articles were included if they: (1) considered scar contractures due to burn and (2) provided the total number of patients admitted to a burn center in a specified inclusion period as well as the number of patients with contractures from this population at a certain moment after the burn. As there is no accepted definition of scar contracture, all descriptions of scar contractures after burn were accepted. Excluded were articles describing:

- Scar contractures after reconstructive surgery for burn;
- Burns of only specific etiology;
- Burns only involving a specific joint.

The titles and abstracts of all records identified by the search were independently screened by two researchers (AMO and MKN) to determine eligibility. Full texts of eligible articles were subsequently screened by at least two reviewers (AMO, LJM, and/or MKN). In all instances, differences of opinions were resolved by discussion.

Data extraction and analyses

Data were extracted regarding study characteristics (i.e., design, patient inclusion period), subject and burn characteristics (i.e., gender, age, extent of burn, number of subjects with a contracture, included joints, number of locations affected by burns with contracture), method of scar contracture assessment, and possible additional determinants. Point prevalence was calculated based on the extracted data including confidence intervals.[17]

Quality assessment

The quality of all of the included articles was scored on five items based on a checklist specifically developed to appraise studies reporting prevalence.[18] These items comprised representativeness and description of the population, data analysis, method and time of assessment and subgroups, and confounders.

RESULTS

Study selection

The computerized literature search initially produced 167 articles which was reduced to 150 after duplicates were removed (Figure 1). Screening titles and abstracts, if necessary, resulted in the exclusion of 135 articles. Two additional articles were identified through other sources. After full text screening, nine articles and one abstract could be included for data extraction. No full text could be traced for the abstract.[19]

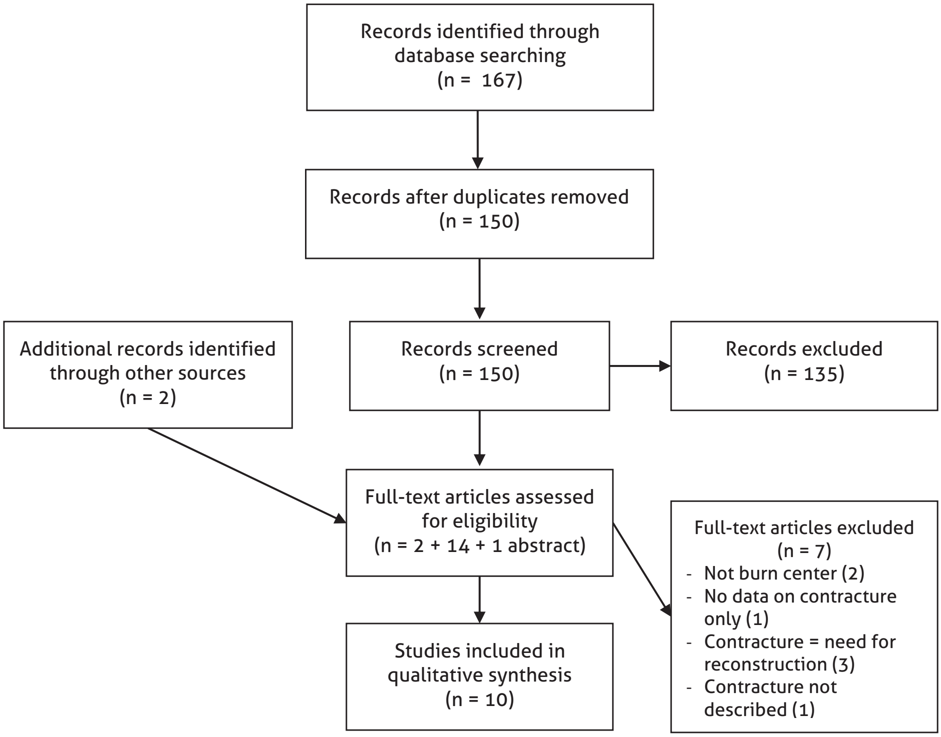

Figure 1 - Flowchart of study selection procedure.

Characteristics of the included studies

Characteristics of the included studies are provided in Table 1. The design of studies was retrospective in five of the studies and prospective also in five. Most of the studies were from the USA (5), but there were also two from Africa, two from Europe, and one from Australia. The decade of patient inclusion varied considerably, ranging from the 1960th/1970th,[6,20-22] up to the 2000s.[1,23,24] The method of scar contracture assessment was ROM in six studies; active ROM in two, passive ROM in one, and unspecified ROM in three of the studies. Furthermore, in three of them, a system was additionally used to classify contracture severity. In four studies, the method of scar contracture assessment was not described. The time of assessment varied between studies, i.e., at discharge (two studies) or at any time during or after recovery. In three studies, the time of assessment was not clear or not specified.

Seven studies had a sample size of more than 100 patients. In the seven studies that specified gender, the majority of subjects were male. The age and extent of a burn, as far as described, covered a wide range.

Subgroups were distinguished in three studies. Dobbs and Curreri[20] identified patients with second and third degree burns, and Kowalske et al.[19] distinguished three

Table 1 - Characteristics of studies, their methods of contracture assessment, and the subjects and their burns.

Study characteristics				Methods		Subject and burn characteristics			
Author	**Design**	**Country**	**Inclusion period**	**Contracture assessment**	**Time of assessment**	**N**	**Gender (male)**	**Age in years**	**%TBSA**
Dobbs 1972[20]	P	USA	1967 - 1968	ROM + severity classification	At time of disposition[a]	681	Maj.[b]	-	-
Pegg 1978[21]	P	Australia	1970 - 1975	-	-	411	71%	-	75% <20
Huang 1978[6]	R	USA	1964 - 1975	ROM + severity classification	After recovery	625	-	-	-
Sowemimo 1983[22]	R	Nigeria	1968 - 1975	-	"Late"	89	67%	56% <15 yr (range: 0-54)	50% <20
Gorga 1999[25]	P	USA	-	P-ROM	1, 6, 12 mo pb	51	61%	Mean: 2.3 (sd: 1.6)	Mean: 6[c] (sd: 4.5)
Kowalske 2003[19]	P	USA	-	Clinical exam incl. A-ROM	At discharge	2559	-	Children, adults, elderly[d]	Major burns[e]
Fatusi 2006[23]	R	Nigeria	1998 - 2003	-	-	139	63%	42% between 10-29 yr	Median: 19 and 25%[f]
Schneider 2006[1]	P	USA	1993 - 2002	A-ROM + severity classification	At discharge[g]	985	78%	Mean: 42.5 (sd: 17.1)	Mean: 25.1 (sd: 19.7)
Gangemi 2008[24]	R	Italy	1994 - 2006	Clinical exam incl. ROM	During follow-up[h]	703	63%	Median: 38 (IQR: 25-54)	Median: 20 (IQR:10-35)
Kidd 2013[26]	R	UK	1995 - 1997	-	At any time until adult age	94	-	Mean: 5.3 (sd: 4.9)	Mean 8.2 (range: <1-70%)

P: prospective study; R: retrospective study; IQR: interquartile range; A, P-ROM: active, passive range of motion; %TBSA: percentage total body surface area burned; yr: years; mo: months; pb: post burn; [a] 80% assessed >2 months after closure burn wounds; [b] Maj.: majority is active duty military personnel; [c] 67% major burns according to the criteria of the American Burns Association; [d] 823 patients < 18 years, 1478 patients 18-60 years, 258 patients >60 years; [e] Major burns according to the criteria of the American Burn Association; [f] Two subgroups considered in the study: patients with and without facial burns; [g] Mean length of stay 21.7 days, sd: 22.9; [h] Median 483 days.

age categories. In the study by Huang et al.[6] four subgroups were described depending on care received: no splinting, less than six months of splinting, 6-12 months of splinting, and more than 12 months of splinting. The <6months splinting group was small compared to the others and identical in outcome to the no splinting group. As the authors themselves also discussed their findings dichotomously, these two groups were combined as were the 6-12 and >12months of splinting groups.

Quality assessment

The quality assessment of all included articles involved five items (Table 2). Two studies could be ascertained as covering a wide range of the burn population.[19,24] In the other studies, only a part of the burn population was represented, or the composition of the study sample was unclear. Subjects and settings were not described in detail in four out of ten studies; this particularly involved the older studies.[6,20-22] Coverage of the identified sample could not be established confidently in an additional two, more recent, studies.[19,25] In the study by Kowalske et al.[19] this was probably due to the fact that no full text article of the study was available. In only four studies could we establish that objective, standard criteria had been utilized for the assessment of scar contracture.[1,19,24,25] Finally, subgroups were specifically distinguished in three studies as described above whereas confounders and other differences were only sufficiently addressed in three additional studies.[1,24,26]

Table 2 - Quality assessment of included studies.

Author	Representative	Detail	Coverage sample	Assessment		Subgroups, confounders
				Method	Time	
Dobbs[20]	In part	-	+	?	+	+
Pegg[21]	In part	-	+	-	-	-
Huang[6]	?	-	+	?	-	-/+
Sowemimo[22]	In part	-	?	-	-	-
Gorga[25]	In part	+	-/+	+	+	-
Kowalske[19]	+	+	?	+	+	+
Fatusi[23]	In part	+	+	-	-	-
Schneider[1]	In part	+	+	+	+	+
Gangemi[24]	+	+	+	+	-	+
Kidd[26]	In part	+	+	-	-	+

Quality assessment items (based on Munn et al.[18])
- Was the sample representative of the target population;
- Were the subjects and the setting described in detail;
- Was the data analysis conducted with sufficient coverage of the identified sample;
- Were objective, standard criteria used for the assessment of the condition;
- Were all important confounding factors, subgroups, differences identified and accounted for.

Prevalence and determinants of scar contractures

For patients after burn, the prevalence of scar contracture at discharge was high (38-54%). With a longer period of time after burn, however, the prevalence of contractures was lower (Table 3). Over almost four decades, when examining two cohorts containing numerous adults,[20,24] there appeared to be no obvious decrease in prevalence during recovery.

Table 3 - Prevalence of scar contractures in patients after burn.

Study characteristics			Prevalence per patient			
Author	**Study group**	**Assessment**	**N**	**N with C**	**PP**	**95% CI**
Dobbs[20]	Adults	During recovery	681	188	28%	±3.4
Pegg[21]	>12years old	-	411	32	8%	±2.6
Huang[6]	• Adults: no or < 6 months splinting	After recovery	270	250	93%	±3.0
	• Adults: >6 months splinting	After recovery	355	60	17%	±3.9
Sowemimo[22]	All ages	''Late''	89	12	13%	±7.0
Gorga[25]	6 months - 6 years old	During recovery[b]	51	2/1/1	4%/2%/2%	±5.4/±3.8/±3.8
Kowalske[19]	• <18 years old, major burns[a]	At discharge	823	440	54%	±3.4
	• Adults, major burns[a]	At discharge	1478	641	43%	±2.5
	• Elderly, major burns[a]	At discharge	258	98	38%	±5.9
Fatusi[23]	All ages	-	139	11	8%	±4.5
Schneider[1]	Adults, major burns[a]	At discharge	985	381	39%	±3.1
Gangemi[24]	All ages	During recovery	703	220	32%	±3.5
Kidd[26]	< 16years old + surgery	Until adulthood	94	17	18%	±7.8

N: number of patients; N with C: number of patients with scar contracture; PP: point prevalence; 95% CI: confidence interval of 95%; [a] Major burns according to the criteria of the American Burns Association; [b] Assessment during recovery per time point: 1, 6 and 12 months after burn.

Determinants of scar contractures found in seven studies are listed in Table 4. In the study comprising a pediatric, an adult, and an elderly group,[19] the prevalence of scar contractures was lowest in the elderly. Multivariate analysis in the study by Gangemi et al.[24] also indicated that older subjects had a significantly lower risk for contracture. Kidd et al.[26] determined that, in children <16years, those that developed scar contractures were significantly younger (82% <5years of age) and had a greater total body surface area (TBSA) burned than children developing hypertrophic or no scarring. In two studies, female were found to have a significantly higher incidence of contractures than male.[21,24] However, in their >60year old group, Kowalske et al.[19] ascertained that female had a lower incidence compared to male.

Table 4 - Determinants of scar contractures after burn.

Author	Age	Gender	Ethnicity	Etiology	Burn severity		LOS	Site of burn
					Extent	Depth		
Dobbs[20]					X	X		X
Pegg[21]		X			X[b]	X[c]		
Huang[6]								X
Kowalske[19]	X	X[a]	X	X	X			X
Schneider[1]					X	X[d]	X	X
Gangemi[24]	X	X		X	X	X		X
Kidd[26]	X				X			X

LOS: length of stay at the hospital; [a] In the >60years old group; [b] In areas with full thickness; [c] In more extensive burns; [d] Extent grafted.

In addition, more scar contractures were found among Hispanics in the <18year old group and among Blacks in the 18-60year old group.[19] Contractures were determined to be more common after flame burns[19,24] and more frequent in more extensive burns either in or not in combination with areas of full thickness burns.[1,19-21,24,26] TBSA burned and grafted together with the length of stay at the hospital were a significant predictor of occurrences of scar contractures.[1]

Dobbs and Curreri[20] specifically investigated the influence of the depth of burn on loss of motion and found that third degree burns showed more scar contractures (34%) than second degree burns (5%) (Table 5). Secondly, Schneider et al.[1] found that joints of the upper extremity, specifically the shoulders and elbows, to be more frequently contracted compared to joints of the lower extremity. They and Kowalske et al.,[19] however, did not specify how many joints were affected by burns. In Table 5, the number of scar contractures per number of locations affected by burns is depicted. Localization does appear to have an influence on prevalence of scar contractures, however, it has not been explicitly substantiated.

Treatment is also a determinant of scar contracture. Gangemi et al.[24] determined that surgical treatment, the number of surgical interventions, timing of excision, and grafting statistically significantly contributed to the occurrence of scar contracture, however, the type of surgery did not. In the study by Huang et al.[6] it was indicated that the duration of splinting influenced prevalence; with longer periods of splinting (and pressure garments), less contractures were found across all joints.

Table 5 - Prevalence of contractures per location affected by burns.

Author	Study group	Total			Per location			
		PP	B with C/B	95%CI	Cervical spine		Shoulder / Axilla	
Dobbs[20]	Adults total	15%	509/3312	±1.2	14%	28/201	S: 19%	114/588
	• 2nd degree	5%	98/2120	±0.9	2%	4/161	S: 6%	27/428
	• 3nd degree	34%	411/1192	±2.7	60%	24/40	S: 4%	87/160
Huang[6]	Adults: no or < 6 mo splinting	80%	457/568	±3.3	-	-	A: 94%	192/204
	Adults: 6-12 mo splinting	30%	201/667	±3.5	-	-	A: 7%	72/154
Gangemi[24]	All ages	19%	473/2440[a]	±1.5	40%	65/162	-	-
Kidd[26]	< 16 yrs + surgery	6%	20/329[a]	±2.6	11%	2/19	S: 10% A: 100%	S: 2/21 A: 7/7

PP: point prevalence; B: number of locations with burns; B with C: number of locations with burns and scar contracture; 95%CI: confidence interval of 95%; mo: months; yrs: years; S: shoulder; A: axilla; [a] Study reported on more burn sites than included in this table, therefore the 'total' is not the sum of the burned sites per location; [b] Wrist and hand.

DISCUSSION

The primary conclusion of this systematic review is that prevalence of contractures is inadequately reported and varies considerably between studies. There are only a minimal number of studies reporting scar contracture prevalence and those that have been conducted cover very heterogeneous patient groups and are primarily of poor methodological quality. The scenario that emerges is that, in patients after burn, prevalence of scar contracture at discharge is high (38-54%). However, after a longer period of time after burn, the prevalence of contractures is lower. Remarkably, over almost four decades, no obvious decrease in prevalence seems evident. Furthermore, contractures were more likely to occur in deep and/or surgically treated burns, at certain joints, and in female and children.

The finding in our review that prevalence of scar contractures is lower with a longer period of time after burn is supported by studies reporting on patients treated for correction of their contracture.[12,27] Kraemer et al.[27] determined that, overall, 4% (31 of 831) of children and adults underwent reconstruction for scar contractures (children 19/243; adults 12/596). Furthermore, the finding in this review indicates that the neck and upper extremity showed a higher incidence than the lower extremity, and the majority of contractures (80%) undergoing surgery developed in areas that had skin grafts. In a recent study by Hop et al.,[12] significant independent predictors for reconstructive surgery based on multivariable regression analyses were: burns to the arms (including hands and shoulders) (Odds Ratio (OR): 3.16), fire/flame burns (OR: 1.50), number of surgical interventions in acute phase, (OR: 1.74) and a higher percentage TBSA burned (OR: 1.02).

Per location											
Elbow		**Wrist**		**Upper limb**		**Knee**		**Foot / Ankle**		**Lower limb**	
15%	130/860	-	-	-	-	8%	47/612	13%	18/139	-	-
4%	23/554	-	-	-	-	2%	5/325	8%	4/49	-	-
35%	107/306					15%	42/287	16%	14/90	-	-
79%	139/176	65%	63/97			69%	63/91	-	-	-	-
28%	48/171	26%	49/185			20%	32/157	-	-	-	-
-	-	-	-	27%	224/834	-	-	-	-	8%	49/606
20%	2/10	7%	2/29[b]	-	-	4%	2/46	6%	2/36	-	-

In addition, the study by Huang et al.[6] suggests that the duration of splinting may influence scar contractures: the group of patients with no or less than six months of splinting had the highest prevalence (over 90%) of all reviewed groups whereas, in the group with splinting for more than six months, prevalence was significantly less: 17%. Richard et al.,[28] in a statistical re-analysis of the data of Huang et al.,[6] indeed found supporting evidence for a positive effect of splinting for at least six months, though no strong conclusions could be drawn. The issue of splinting, however, is (still) under debate; in our earlier review,[3] we pointed out the lack of randomized controlled clinical trials for evidence of the effectiveness of splinting and, secondly, that mechanical tension, as in splinting, may actually stimulate myofibroblast activity and thus induce or maintain scar contracture. Furthermore, the first randomized controlled trial concerning splinting and contractures of the shoulder recently conducted by Kolmus et al.,[9] provided evidence that splinting was no more or even less effective than exercise alone. Either way, there is strong consensus on the need for research on the clinical efficacy of (duration of) splinting concerning scar contracture.

The primary limitation of our review is that we choose for a search strategy focused on prevalence in general and not search for burns of specific etiology or body areas/joints. The current search strategy did identify some articles concerning specific joints i.e., hand (palm),[13,29] neck,[30] feet[31] and etiology (e.g., flammable liquid burns[32]). These did not provide new information, but as our search strategy was not developed to identify all such studies, it might be that there exist studies that do contain additional information.

There are a number of obstacles regarding studies on prevalence of scar contracture and thus also regarding (the evaluation of) treatment outcomes. First of all, despite the fact that this problem has been noted for several years (e.g., Schneider et al.[1]), no worldwide accepted definition and operationalization of contracture is yet available. For example, contracture severity is classified using different cut off points,[1,6] and these are not related to function. Fortunately, efforts are being made to remedy this.[33,34] A second, but related, problem as reviewed by Parry et al.[35] as well as is evident from this review is that methods to assess scar contractures are inadequately described and, moreover, that different methods are used.

Our finding that information concerning the prevalence of scar contractures is scarce and varies considerably urges for the development of national and international registration. When the prevalence is unclear, it is also difficult to investigate potential determinants and to evaluate changes in interventions. There is a need for extensive, well-designed studies that investigate the prevalence of scar contracture. To improve methodological quality, future studies should follow the STROBE guidelines on reporting.[36] Patient and burn characteristics should be described in detail including localization of burn, localization of scar contracture, and standardized methods of assessment. Furthermore, beside the standard risk factors such as gender, depth and extent of burn, preferably also amendable factors such as the type of surgery should be included. Ideally, information on the presence and extent of scar contractures is combined with functional assessment and patient perception of the problem. Longitudinal studies would be very beneficial to investigate how scar contractures evolve over time.

CONCLUSION

The prevalence of scar contractures after burn is insufficiently reported and varies considerably between studies. When prevalence is unclear, it is also difficult to investigate potential determinants and to evaluate changes in interventions. There is a need for substantial, well-designed longitudinal (inter)national studies that investigate the prevalence of scar contracture, its evolvement over a period of time, and the risk factors. Furthermore, a worldwide accepted definition and operationalization of contractures is required in which the severity is classified based on the functional outcomes.

Authors contributions

MKN and HS conceived of the study, and MKN participated in its design and coordination. AMO carried out the literature search and together with LJM and MKN appraised the articles and drafted the manuscript. HS, CPvdS and LMD contributed to the analysis and interpretation of the data and revising the draft critically. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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REFERENCES

1. Schneider JC, Holavanahalli R, Helm P, Goldstein R, Kowalske K. Contractures in burn injury: defining the problem. J Burn Care Res. 2006;27:508-14.
2. Leblebici B, Adam M, Bagis S, Tarim AM, Noyan T, Akman MN, et al. Quality of life after burn injury: the impact of joint contracture. J Burn Care Res. 2006;27:864-8.
3. Schouten HJ, Nieuwenhuis MK, van Zuijlen PP. A review on static splinting therapy to prevent burn scar contracture: do clinical and experimental data warrant its clinical application? Burns. 2012;38:19-25.
4. Palmieri TL, Petuskey K, Bagley A, Takashiba S, Greenhalgh DG, Rab GT. Alterations in functional movement after axillary burn scar contracture: a motion analysis study. J Burn Care Rehabil. 2003;24:104-8.
5. Fischer U, Müller M, Strobl R, Bartoszek G, Meyer G, Grill E. Examining functioning and contextual factors in individuals with joint contractures from the health professional perspective using the ICF: an international internet-based qualitative expert survey. Rehabil Nurs. 2016;41:170-8.
6. Huang TT, Blackwell SJ, Lewis SR. Ten years of experience in managing patients with burn contractures of axilla, elbow, wrist, and knee joints. Plast Reconstr Surg. 1978;61:70-6.
7. Richard R, Miller S, Staley M, Johnson RM. Multimodal versus progressive treatment techniques to correct burn scar contractures. J Burn Care Rehabil. 2000;21:506-12.
8. Dewey WS, Richard RL, Parry IS. Positioning, splinting, and contracture management. Phys Med Rehabil Clin N Am. 2011;22:229-47.
9. Kolmus AM, Holland AE, Byrne MJ, Cleland HJ. The effects of splinting on shoulder function in adult burns. Burns. 2012;38:638-44.
10. Lester ME, Hazelton J, Dewey WS, Casey JC, Richard R. Influence of upper extremity positioning on pain, paresthesia, and tolerance: advancing current practice. J Burn Care Res. 2013;34:e342-50.
11. Godleski M, Oeffling A, Bruflat AK, Craig E, Weitzenkamp D, Lindberg G. Treating burn-associated joint contracture: results of an inpatient rehabilitation stretching protocol. J Burn Care Res. 2013;34:420-6.
12. Hop MJ, Langenberg LC, Hiddingh J, Stekelenburg CM, van der Wal MB, Hoogewerf CJ, et al. Reconstructive surgery after burns: a 10-year follow-up study. Burns. 2014;40:1544-51.
13. Schneider JC, Holavanahalli R, Helm P, O'Neil C, Goldstein R, Kowalske K. Contractures in burn injury part II: investigating joints of the hand. J Burn Care Res. 2008;29:606-13.
14. Schneider JC, Qu HD, Lowry J, Walker J, Vitale E, Zona M. Efficacy of inpatient burn rehabilitation: a prospective pilot study examining range of motion, hand function and balance. Burns. 2012;38:164-71.
15. Esselman PC, Thombs BD, Magyar-Russell G, Fauerbach JA. Burn rehabilitation: state of the science. Am J Phys Med Rehabil. 2006;85:383-413.
16. Shakirov BM. Foot postburn bent contracture deformities. Burns. 2007;33:1054-8.
17. McCallum-Layton. https://www.mccallum-layton.co.uk/tools/statistic-calculators/confidence-interval-forproportions-calculator/ [accessed June 2015].
18. Munn Z, Moola S, Riitano D, Lisy K. The development of a critical appraisal tool for use in systematic reviews addressing

questions of prevalence. Int J Health Policy Manag. 2014;13:123-8.
19. Kowalske K, Holavanahalli R, Sergio M, Esselman P, Ware L, Delateur B, et al. Contractures following burn injury in children and adults. J Burn Care Res. 2003;24:S85.
20. Dobbs ER, Curreri PW. Burns analysis of results of physical therapy in 681 patients. J Trauma. 1972;12:242-8.
21. Pegg SP, Gregory JJ, Hogan PG, Mottarelly IW, Walker LF. Epidemiological pattern of adult burn injuries. Burns. 1978;5:326-34.
22. Sowemimo GO. Burn injuries in Lagos. Burns. 1983;9:280-3.
23. Fatusi OA, Fatusi AO, Olabanji JK, Alatise OI. Management outcome and associated factors in burn injuries with and without facial involvement in a Nigerian population. J Burn Care Res. 2006;27:869-76.
24. Gangemi EN, Gregori D, Berchialla P, Zingarelli E, Cairo M, Bollero D, et al. Epidemiology and risk factors for pathologic scarring after burn wounds. Arch Facial Plast Surg. 2008;10:93-102.
25. Gorga D, Johnson J, Bentley A, Silverberg R, Glassman M, Madden M, et al. The physical, functional, and developmental outcome of pediatric burn survivors from 1 to 12 months postinjury. J Burn Care Rehabil. 1999;20:171-8.
26. Kidd LR, Nguyen DQ, Lyons SC, Dickson WA. Following up the follow up - long-term complications in paediatric burns. Burns. 2013;39:55-60.
27. Kraemer MD, Jones T, Deitch EA. Burn contractures: incidence, predisposing factors, and results of surgical therapy. J Burn Care Rehabil. 1988;9:261-5.
28. Richard R, Dewey S, Parry I, Jones J. Letter to the editor. Burns. 2013;39:539-41.
29. Barret JP, Desai MH, Herndon DN. The isolated burned palm in children: epidemiology and long-term sequelae. Plast Reconstr Surg. 2000;105:949-52.
30. Bunchman 2nd HH, Huang TT, Larson DL, Lewis SR. Prevention and management of contractures in patients with burns of the neck. Am J Surg. 1975;130:700-3.
31. Gore D, Desai M, Herndon DN, Abston S, Evans EB. Comparison of complications during rehabilitation between conservative and early surgical management in thermal burns involving the feet of children and adolescents. J Burn Care Rehabil. 1988;9:92-5.
32. Henderson P, Mc Conville H, Höhlriegel N, Fraser JF, Kimble RM. Flammable liquid burns in children. Burns. 2003;29:349-52.
33. Niedzielski LS, Chapman MT. Changes in burn scar contracture: utilization of a severity scale and predictor of return to duty for service members. J Burn Care Res. 2015;36:e212-9.
34. Korp K, Richard R, Hawkins D. Refining the idiom functional range of motion related to burn recovery. J Burn Care Res. 2015;36:e136-45.
35. Parry I, Walker K, Niszczak J, Palmieri T, Greenhalgh D. Methods and tools used for the measurement of burn scar contracture. J Burn Care Res. 2010;31:888-903.
36. Elm von E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. STROBE initiative. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. Lancet. 2007;370:1453-7.

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Shoulder and elbow range of motion for the performance of activities of daily living: a systematic review

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ABSTRACT

The loss of range of motion (ROM) in the upper extremities can interfere with activities of daily living (ADL) and, therefore, many interventions focus on improving impaired ROM. The question, however, is what joint angles are needed to naturally perform ADL. The present review aimed to compile and synthesize data from literature on shoulder and elbow angles that unimpaired participants used when performing ADL tasks. A search was conducted in PubMed, Cochrane, Scopus, CINAHL, and PEDro. Studies were eligible when shoulder (flexion, extension, abduction, adduction) and/or elbow (flexion, extension) angles were measured in unimpaired participants who were naturally performing ADL tasks, and angles were provided per task. Thirty-six studies involving a total of 66 ADL tasks were included. Results demonstrated that unimpaired participants used up to full elbow flexion (150°) in personal care, eating, and drinking tasks. For shoulder flexion and abduction approximately 130° was necessary. Specific ADL tasks were measured often, however, almost never for tasks such as dressing. The synthesized information can be used to interpret impairments on the individual level and to establish rehabilitation goals in terms of function and prevention of secondary conditions due to excessive use of compensatory movements.

INTRODUCTION

An adequate active range of motion (ROM) in all directions in the upper extremity joints is necessary to perform all types of activities of daily living (ADL).[1,2] When daily tasks such as eating, drinking, dressing, or personal care are impeded due to decreased ROM, then the activity must either be performed by using compensatory movement strategies,[3-8] with the assistance of adaptive instruments or with help from other people. Each of these solutions might initially be considered as adequate, however, in the long term, they may all have physical, psychological, social, and/or financial disadvantages. For example, compensatory movements can lead to serious secondary conditions such as the overuse of muscles around the affected joint and an increased risk of soft tissue problems and degenerative joint diseases.[5,9,10] Therefore, maintaining or restoring the ROM of joints is often a treatment goal in physical rehabilitation. However, this goal is usually established in terms of maximal ROM while, in fact, maintaining or restoring the minimal ROM necessary for the ADL of an individual could be sufficient. To set such ADL-related goals, reference values for minimally required ROM per ADL task are necessary.

Impaired ROM can occur at all ages as a consequence of medical conditions such as skin contractures due to a burn injury, muscle shortness, tendon or ligament contractures, adhesive capsulitis, bone fractures, plexus lesions, pain, or (neuromuscular) diseases such as cerebral palsy, rheumatoid arthritis, spinal cord injury, and others.[11-18] Residual pathologic motion patterns of upper extremity joints may persist following rehabilitation for patients who have experienced a stroke[19] and after arthroplasty of the shoulder in patients with degenerative osteoarthritis.[20]

ROM is usually assessed as the degree of maximal mobility of a specific joint in a particular plane of movement. Although these measurements provide clinicians with valuable data, they do not specify information regarding the functional capacities of the individual patient in daily living. For instance, one patient with impaired shoulder flexion motion may not be able to raise an upper limb as far as unimpaired participants but may still be able to normally execute almost all ADL tasks. Whereas, on the other hand, another patient with approximately the same impairments can be physically disabled due to different demands of daily activities, for example, living in a house with many high cupboards. Furthermore, information concerning activity limitations is often gathered by questionnaires and/or by assessing a patient's performance on a small set of ADL tasks. However, from questionnaires, no insight into possible harmful movement patterns can be gained and, when using a small set of ADL tasks, knowledge on which set is most appropriate should be available.

In 1981, Morrey et al.[21] had already drawn attention to the issue of functional ROM and performed an extensive study in which elbow angles of different movement directions were measured while participants (age range 21-75 years) performed 15 different ADL tasks. Since that time, the data of this study have been used as a reference. However, the use of these data is limited as only the elbow was assessed, and the 15 tasks that were analyzed did not address full ADL. Over the past decades, numerous additional studies have been conducted in which upper extremity joint angles were measured in (simulated) ADL tasks. In 2015, Korp et al.[22] conducted a systematic review on functional ROMs in ADL for all upper and three lower extremity joints in the context of rehabilitation after burn injury. Per joint, they reported the tasks of upper and lower impairments of ROM with corresponding angles. Although this is valuable information, it does not provide full insight into the used ROMs of each specific ADL task and, therefore, does not allow individualized choices for required ROM based on function. Moreover, there is an impression that, for at least shoulder and elbow, additional data could have been discovered by conducting a literature search more specifically focusing on these joints. Therefore, the present review aimed to compile and synthesize data from literature on shoulder and elbow angles used by unimpaired participants performing ADL tasks.

METHODS

For this systematic review, the process described in 'Preferred Reporting Items for Systematic Reviews & Meta-Analysis (PRISMA)' was used.[23] Ethics Committee(s) approval is 'Not Applicable' as the present study is a systematic review.

Databases and search strategy

A computerized literature search was conducted including the databases of PubMed, Cochrane, Scopus, CINAHL, and PEDro. Combinations of the following keywords and free text words were used: ADL; upper extremity; and ROM. Additionally, the words function, shoulder, and elbow were searched. The searches in the different databases were conducted from December 2014 to February 2015 (Appendix 1 for MeSH terms and number of retrieved studies per database). Furthermore, references of the retrieved studies were manually screened by two authors (AMO, LJM) and experts in the field were consulted.

Inclusion criteria and process of selection

The title and abstract were screened independently by two authors (AMO, LJM) focusing on unimpaired participants (investigated as the primary study group or control group of a randomized controlled trial (RCT)) performing ADL tasks in which shoulder and elbow angles were measured. Discrepancies were resolved with a discussion between the two reviewers and, in the event of uncertainty, the study was included for full text screening. The full text of potentially relevant studies was screened based on the more specific predefined inclusion criteria: 1) unimpaired participants performed ADL tasks without restriction of brace or splint; and 2) shoulder (thoracohumeral) and/or elbow angles were measured continuously and the maximal angles per joint and per movement direction were reported per task.

Assessment of quality of reviewed studies

The present review concerned cross-sectional observational studies. For this type of study, unlike RCTs or other clinical studies, no standard scales or checklists to assess quality or control for confounding variables were available.[24,25] To be able to include quality assessment of studies, the recommendations of Sanderson et al.[24] were followed to assess the risk of bias (ROB) using a self-developed checklist covering the three most fundamental domains (i.e., participants, measurements of variables, and control of confounding). The categories included were: 1) representativeness of the study population; 2) hand dominance and prescription of the movement strategy; and 3) reliability of the methods used and definitions of measured angles. Methodological quality was appraised independently by two authors (AMO, LJM).

Data extraction

Data was extracted by one reviewer (AMO) regarding participant characteristics (number of participants, gender, age), methods (tracking system, number of ADL tasks that could be analyzed in this review, upper limb assessment), and the means (and standard deviations if reported in table or text) of joint angles of shoulder flexion, extension, abduction and adduction, and elbow flexion and extension. Graphically reported joint angles were extracted as accurately as possible and, if necessary, by enlarging the graph. A second reviewer (LJM) verified the extracted data.

Extraction of angles of shoulder motion

Although the unambiguous method to describe shoulder movements in 3D is in terms of plane of elevation (PoE) and angle of elevation,[26,27] many studies described them in terms of flexion and extension as well as abduction and adduction. As in clinical practice this continues to be the most used description, therefore, in the present review, all reported shoulder movements were translated into the latter terminology. Angles of elevation in a PoE ≤ -45° were translated in terms of shoulder extension. Similarly, angles of elevation in a PoE between 45° and 135°, between -45° and 45°, and >135° were translated in terms of shoulder flexion, abduction, or adduction, respectively (Figure 1A-C).

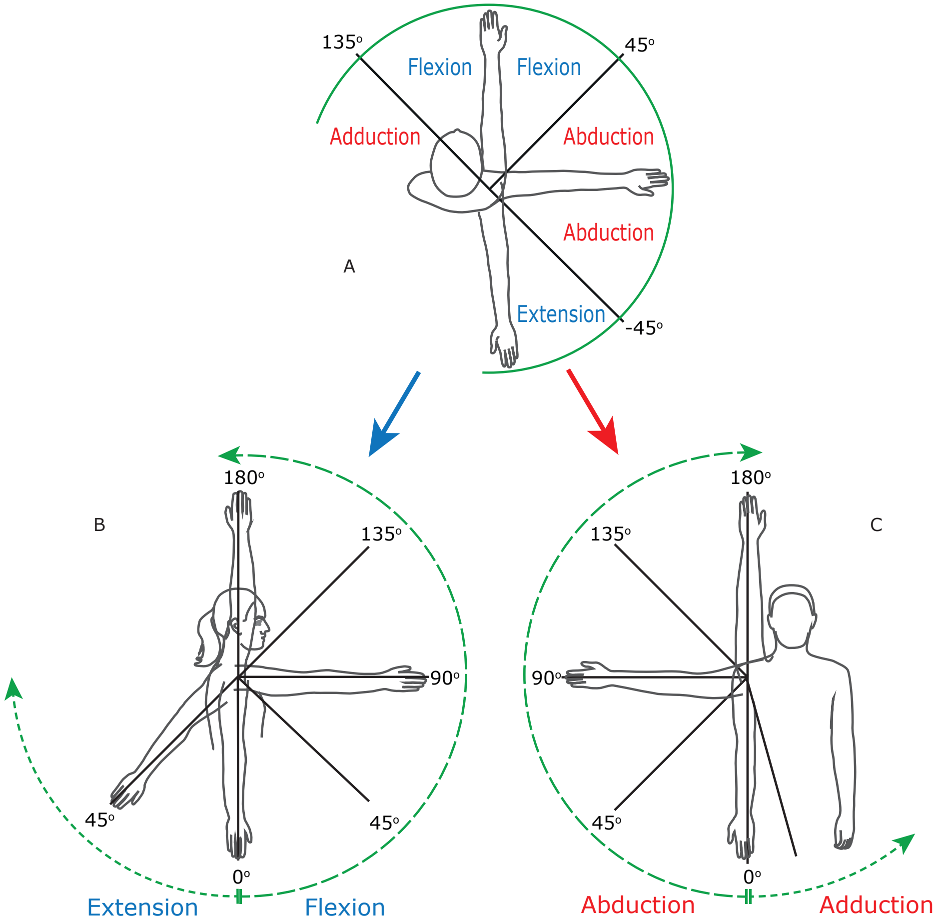

Figure 1 - Movement directions of the shoulder. **A**: Transformation of planes of elevation (PoE) in shoulder extension (PoE≤-45°), flexion (45°<PoE≤135°), abduction (−45°<PoE≤45°) and adduction (PoE>135°). **B**: Angles of extension and flexion (sagittal view). **C**: Angles of abduction and adduction (frontal view).

Extraction of angles of elbow motions

In the literature, elbow movements are described in terms of flexion and extension. However, discrepancies exist on the definition of 0°. In the present review, 0° was established according to the anatomical posture (Figure 2). In the event of doubt regarding the reported movement direction, decisions on the translations were made after the execution of the task and discussion between two researchers (AMO, LJM).

Outcomes

The primary outcome of interest was the required shoulder and/or elbow angle per movement direction while performing a specific ADL task. For all movement direc-

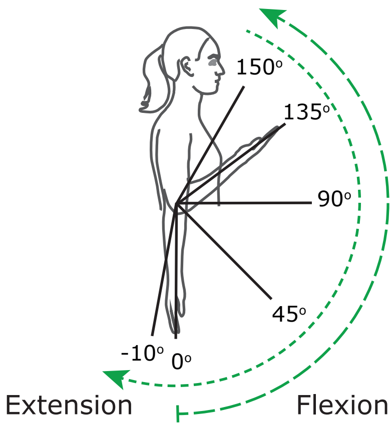

Figure 2 - Movement directions of the elbow: angles of flexion and extension.

tions, this signified the largest measured angle per task except for elbow extension in which the smallest measured angle per task was the primary outcome of interest.

Data analysis and synthesis

For data analysis, tables organized per joint per movement direction were made, presenting an overview of all of the studies that measured required angles in ADL. Measured ADL tasks were clustered into two categories: 1) personal care and feeding tasks; or 2) daily, leisure, and work activities. If ADL tasks were simulated (i.e., merely touching a body part instead of performing the actual task) the tasks were listed under the most adequate category. Data synthesis was employed in order to generate an overview in figures showing the required angles per joint per movement direction per ADL task.

RESULTS

The search strategy in the different databases resulted in a total of 583 potentially relevant studies (Figure 3). After screening the titles and abstracts, 543 were excluded. Full text screening of the remaining 40 studies meant that 27 studies could be included. Screening the reference lists of these revealed a further nine, thus a total of 36 studies were included in the present review (Tables 1 and 2). From the 36 included studies, three[28-30] reported data of two participant groups (differing in either age or gender). Three other studies[31-33] described data of the same participants, therefore, these studies were considered as one study group. The same applied for both studies of Maier et al.[34,35] Hence, in total, the present review yielded data on 36 study groups (Tables 1 and 2).

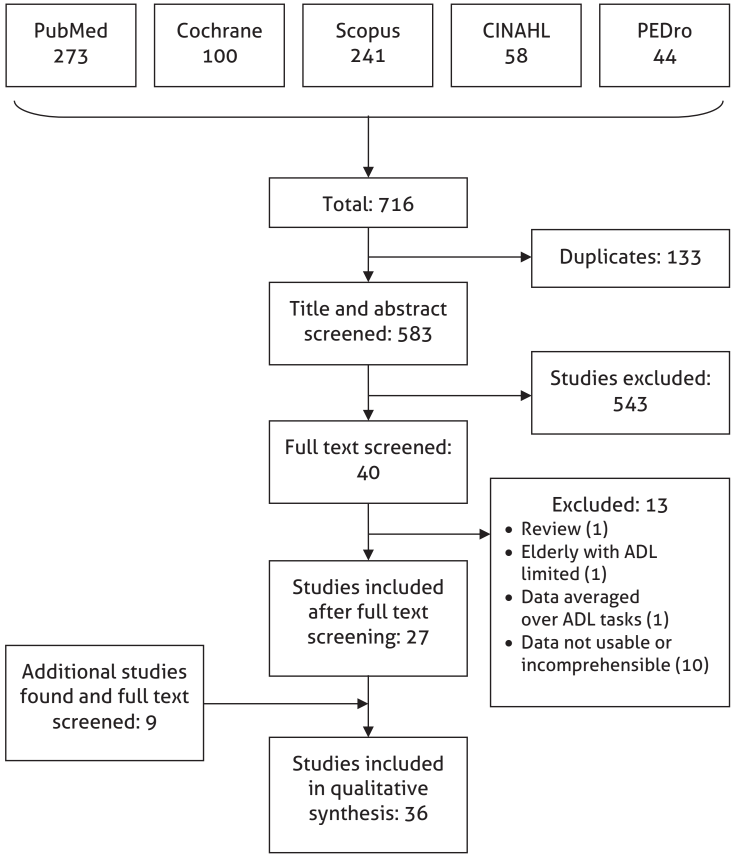

Figure 3 - Flowchart of search strategy showing databases searched and number of papers retrieved from each database, papers rejected and papers reviewed.

Risk of bias

The outcomes of the ROB assessment (Table 1) indicated that the representability of participants in four study groups was good (i.e., low ROB). In 28 study groups, this ROB was considered moderate either due to a small number of participants (<20) and/or the age and/or gender was not representative for the conclusions that were drawn. For instance, a conclusion was drawn for 'adults' even though the (vast) majority of participants were male and/or the range of ages indicated only young adults. For four study groups, the ROB on representability of participants was high. The ROB on study confounders (i.e., the performance of the ADL task with the dominant hand using a self-selected movement strategy) was low in approximately 16 of the study groups and moderate in 18. In two study groups, this ROB was considered high as tasks were performed with the non-dominant hand, and the movement strategy was instructed for parts of the ADL tasks or they needed to be performed as quickly as possible.

In almost all of the study groups, reliability of the methods used and definitions of measured angles were judged to be good (i.e., low ROB).

Study and participant characteristics

The number of participants per study group varied between three and 59 with less than 20 participants in 25 study groups. The majority of the study groups consisted of adults (Table 2). The measurement of angles was performed with optical 3D tracking systems in all of the studies except for Morrey et al.[21] who measured with an electro-goniometer. The number of analyzed ADL tasks per study group that could be included ranged from 1 to 18. In 26 study groups, upper extremity kinematics were measured while the ADL tasks were performed with the dominant upper limb, primarily the right upper limb. For eight groups, no information on dominance was provided and either left, right, or both upper limbs were studied (Table 2).

Table 1 - Quality assessment (i.e., risk of bias) of the 36 included studies.

Year	Authors	Study group	A) ROB representability of participants	B) ROB study confounders	C) ROB measurements
1981	Morrey et al.[18]	Adults + Elderly	+ / -	+	+ / -
1990	Safaee-Rad et al.[36]	Male	+ / -	+	+
1993	Cooper et al.[28]	Male	+ / -	+	+
		Female	+ / -	+	+
2003	King et al.[37]	Female	+	+ / -	+
2003	Palmieri et al.[38]	Children	+ / -	+ / -	+
2004	Mosqueda et al.[39]	Children	+ / -	+ / -	+
2005	Magermans et al.[12]	Female	+	+ / -	+
2006	Henmi et al.[40]	Adults	+ / -	+ / -	+
2007	Lee et al.[29]	Adults	+ / -	+	+
		Elderly	+ / -	+	+
2007	Petuskey et al.[14]	Children	+ / -	+ / -	+
2007/ 9/10	Raiss et al.[31]/ Kasten et al.[32]/ Raiss et al.[33]	Children + Adults	-	+	+
2008	van Andel et al.[15]	Adults	+ / -	+ / -	+ / -
2008	Carey et al.[41]	Adults	+ / -	+ / -	+
2008	Sheikhzadeh et al.[42]	Adults	+ / -	+ / -	+
2009	Muller Rath et al.[30]	Male	+ / -	+	+
		Female	+ / -	+	+
2010	Aizawa et al.[43]	Adults	+ / -	+	+
2010	Murgia et al.[44]	Adults	+ / -	+	+
2010	Raminez-Garcia et al.[45]	Adults	+ / -	+	+
2010	Reid et al.[46]	Children	+ / -	+	+
2010	Sinha et al.[47]	Adults	+	+ / -	+

Table 1 - Quality assessment (i.e., risk of bias) of the 36 included studies. (*continued*)

Year	Authors	Study group	A) ROB representability of participants	B) ROB study confounders	C) ROB measurements
2011	Hall et al.[48]	Elderly	+ / -	+	+ / -
2011	Masjedi et al.[49]	Adults	+ / -	+ / -	+ / -
2011	Murphy et al.[50]	Adults + Elderly	+ / -	+	+
2011	Sardelli et al.[51]	Adults	+ / -	+ / -	+
2012	Karner et al.[52]	Adults	-	+ / -	+
2012	Namdari et al.[53]	Adults	+ / -	+ / -	+
2014	Artiheiro et al.[54]	Adults	-	+ / -	+
2014	Bergsma et al.[55]	Adults	+ / -	+	+
2014	Kim et al.[56]	Adults	+	+ / -	+
2014	Klotz et al.[57]	Children	-	-	+
2014	Lobo-Prat et al.[58]	Male	+ / -	+ / -	+
2014a/ 14b	Maier et al.[34]/ Maier et al.[35]	Adults + Elderly	+ / -	+ / -	+
2014	Major et al.[59]	Adults	+ / -	-	+

ROB: Risk of Bias; +: Risk of Bias is low; +/-: Risk of Bias is moderate; -: Risk of Bias is high. A) Risk of Bias representability of participants. Low: ≥20 participants and good representability on both age and gender. Moderate: ≥20 participants and no representability on age and/or gender / <20 participants and no representability on age or gender; High: <20 participants and no representability on both age and gender. B) Risk of Bias study confounders. Low: dominant hand used and self-chosen movement strategy. Moderate: data dominant and non-dominant mixed or dominance not mentioned or prescription of movement strategy. High: data dominant and non-dominant mixed, or hand(s) and/or dominance not mentioned and prescription on movement strategy. C) Risk of Bias measurements. Low: reliability 3D measures good and definition of all measured angles given. Moderate: reliability 3D measures unknown or definition of (part of the) measured angles unclear. High: reliability 3D measures unknown and definition of all measured angles unclear.

ADL tasks analyzed

Shoulder and elbow angles were analyzed for 66 different (simulated) ADL tasks of which 40 focused on personal care, seven on feeding, and 26 on a wide variety of daily, leisure, and work activities. Only 16 out of the 66 (24%) ADL tasks were analyzed in four or more study groups. The remaining tasks were studied in only one, two, or three study groups.

Concerning tasks studied in four or more study groups, the results of tasks performed in different study groups were generally quite similar (Appendix 2A-F). However, a number of significant differences were also determined. If outlier angles were not likely while performing that specific task, the ROB was used to decide whether or not these data points could be influenced by a confounder and, therefore, excluded for further analysis. This was the case for eight data points (see footnote of Appendix 2C, E, F).

Table 2 - Study and participant characteristics of the 36 studies reviewed.

Reference			Participant characteristics					Method		
Year	Authors	State, Country	N	Gender: %male	Age (years) Mean	SD	Range	Tracking system	Number of ADL tasks*	Upper Limb
1981	Morrey et al.[18]	Minnesota, USA	33	45			21-75	Triaxial electrogonio meter	15	D-L,R
1990	Safaee-Rad et al.[36]	Canada	10	100			20-29	n.m.	3	D-R
1993	Cooper et al.[28]	Canada	10	100			18-50	UM²AS	3	D-R
			9	0			18-50	UM²AS	3	D-R
2003	King et al.[37]	Ohio, USA	59	0	27.5	9.9	20-50	M.A.C.	2	D-R
2003	Palmieri et al.[38]	California, USA	49	n.m.			5-18	ExpertVision	2	L,R
2004	Mosqueda et al.[39]	California, USA	51	n.m.	11.3		5-18	ExpertVision	3	L,R
2005	Magermans et al.[12]	The Netherlands	24	0	36.8	11.8		Flock of Birds	6	R
2006	Henmi et al.[40]	Japan	5	40	23		20-28	Vicon	3	L,R
2007	Lee et al.[29]	Korea	16	100	26.9	2.6		M.A.C.	3	D
			12	50	67.9	4.8		M.A.C.	3	D
2007	Petuskey et al.[14]	California, USA	28	n.m.			9-12	M.A.C.	5	L,R
2007/ 2009/ 2010	Raiss et al.[31]/ Kasten et al.[32] / Raiss et al.[33]	Germany	7	n.m.	25	15	13-54	Vicon	10	D-R
2008	van Andel et al.[15]	The Netherlands	10	60	28.5	5.7		Optotrak	4	D-R
2008	Carey et al.[41]	Florida, USA	10	60	28	7.4		Vicon	3 out of 4	D-R
2008	Sheikhzadeh et al.[42]	New York, USA	8	75	32		25-40	Motion Monitor	8	D
2009	Muller Rath et al.[30]	Germany	8	100	25.5	2.9		Vicon	2	D-L,R
			8	0	26.8	2.7		Vicon	2	D-L,R
2010	Aizawa et al.[43]	Japan	20	50	23	5	18-34	FASTRAK	16	D-R
2010	Murgia et al.[44]	UK	6	n.m.	32.5	10.7		Vicon	1	D
2010	Ramirez-Garcia et al.[45]	Mexico	5	40			24-32	APAS	5	D-R

Table 2 - Study and participant characteristics of the 36 studies reviewed. (*continued*)

Reference			Participant characteristics					Method		
Year	Authors	State, Country	N	Gender: %male	Age (years) Mean	SD	Range	Tracking system	Number of ADL tasks*	Upper Limb
2010	Reid et al.[46]	Perth, Australia	10	50	10.5	1.2		n.m.	3	D
2010	Sinha et al.[47]	UK	20	50	33.3		17-60	Polemus 3 Space Fastrak	18	n.m.
2011	Hall et al.[48]	Canada	13	69			66-93†	Vicon	6	D-R
2011	Masjedi et al.[49]	UK	12	83	43	15.8		Vicon	12	R
2011	Murphy et al.[50]	Sweden	19	57	53		41-78	M.A.C.	1	D-R
2011	Sardelli et al.[51]	Salt Lake City, USA	25	56	34	10		Vicon	17	D
2012	Karner et al.[52]	Austria	15	73	24.1	1.5		Lukotronic	3 out of 4	D-R
2012	Namdari et al.[53]	Pennsylvania, USA	20	90	29.2	1.9	26-34	FASTRAK	6 out of 10	D-L,R
2014	Artiheiro et al.[54]	Brazil	11	18	24.1	3.7		Vicon	1	D-R
2014	Bergsma et al.[55]	Netherlands	8	63	49.9	9.8		Vicon	2 out of 4	D-R
2014	Kim et al.[56]	Korea	32	53	25.3	2.4		Vicon	1	D-L,R
2014	Klotz et al.[57]	Germany	17	65	13		9-17	Vicon	5 out of 6	ND
2014	Lobo-Prat et al.[58]	Spain	3	100	n.m.			BTS SMART-D	1	L
2014a/ 2014b	Maier et al.[34]/ Maier et al.[35]	Germany	10	50	64.2	7		Vicon	4	D-R
2014	Major et al.[59]	Chicago, USA	6	50	35	11		M.A.C.	1 out of 5	ND

*: Number of ADL tasks that could be analyzed in this review; †: Age range of patients and control participants; n.m.: not mentioned; M.A.C.: Motion Analysis Corporation; L: Left; R: Right; D: Dominant; ND: Non Dominant.

Not all tasks were analyzed for all shoulder and elbow movement directions. For the shoulder, the required angles of flexion, extension, abduction, and adduction were analyzed in 30, 10, 23, and 4 study groups, respectively (Appendix 2A-D). Concerning the elbow, required flexion angles were analyzed in 26 study groups and extension in 21 (Appendix 2E-F).

Joint angles required in ADL

Shoulder and elbow angles per (simulated) ADL task used by unimpaired participants are exhibited in Figure 4A-D.

Shoulder angles

Shoulder flexion angles <25° were not found for any of the ADL tasks, and angles of >45° were extracted in 34 of the 39 ADL tasks (Figure 4A). For nine tasks, angles between 90° and 135° were determined. The latter primarily involved tasks of personal care whereby the participant's hand needed to be placed on the upper body or head but also comprised typing on a keyboard, turning a key, and turning a page. A maximal flexion angle of 142° was measured for 'reaching above shoulder level to a shelf'. Shoulder extension angles were extracted for only 11 different ADL tasks. In eight of these tasks involving personal care, angles >40° were found (Figure 4A). Abduction angles >45° were ascertained in 15 of the 28 ADL tasks that included this movement direction (Figure 4B) while participants were able to perform all eating and drinking tasks with <45°. The greatest abduction angles of approximately 125° were required for 'placing the hand behind the head' and 'combing hair'. Adduction was only measured in four ADL tasks. The largest reported angle was for 'washing the contralateral axilla' (116°) (Figure 4B).

Elbow angles

The performance of many ADL tasks required a high degree of elbow flexion (Figure 4C). From the 45 tasks studied, only two tasks required a flexion angle <45°, and six required an angle between 45° and 90°. From the remaining 37 tasks, 16 needed a flexion angle of ≥135°. These latter mainly comprised tasks needed for personal care and feeding, though the largest angle was determined for 'using a telephone'. For 28 tasks, elbow extension was performed. During task performance, an angle of <20° was required for completing reaching tasks, touching one's own shoes or toes, opening a door, and turning a steering wheel (Figure 4D). Hyperextension of the elbow was not measured during any task.

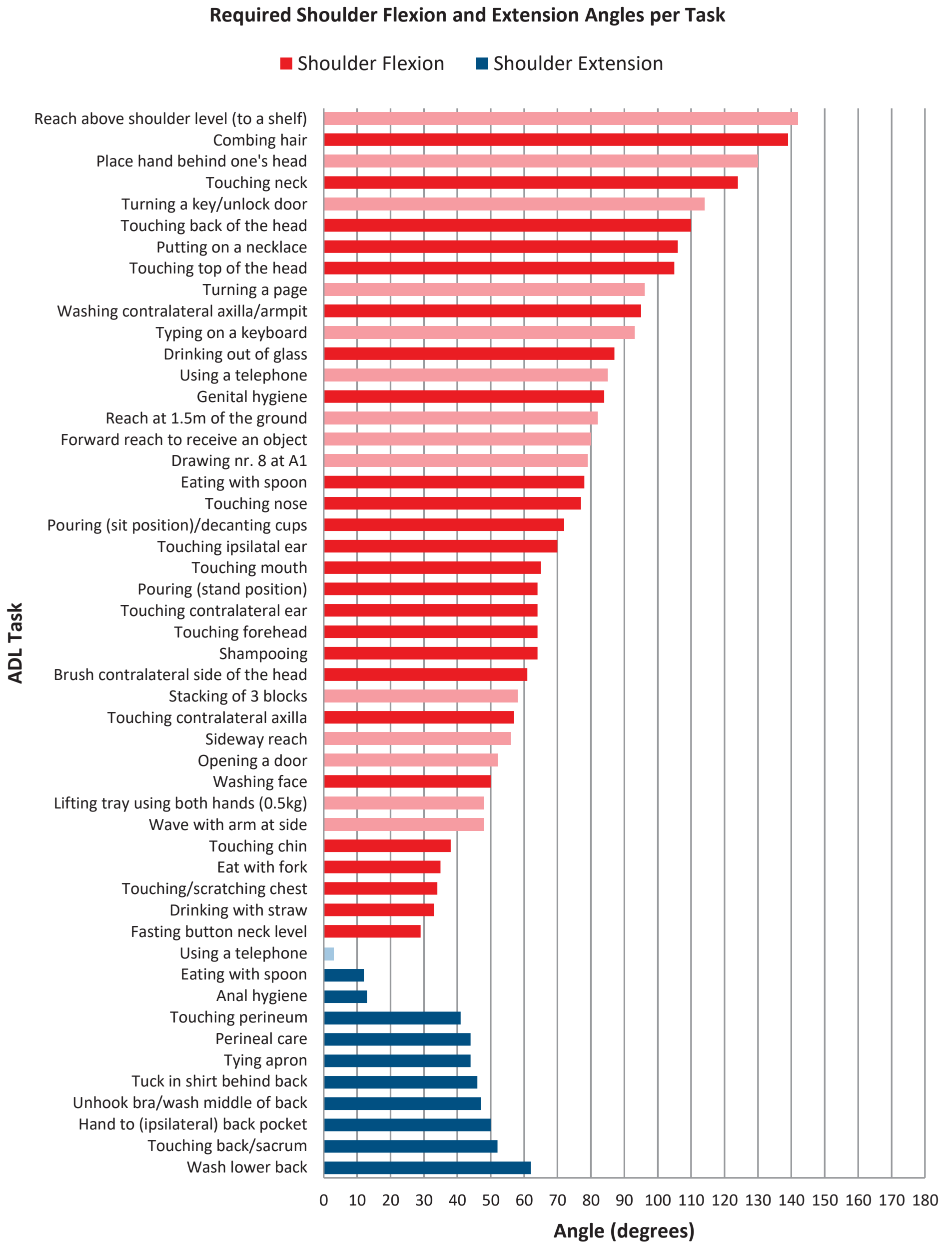

Figure 4(A) - Shoulder and elbow angles per (simulated) ADL task used by unimpaired participants. Dark red and dark blue bars represent personal care and feeding tasks. Light red and light blue bars represent daily, leisure, and work activities. **A**: Shoulder flexion and extension. **B**: Shoulder abduction and adduction. **C**: Elbow flexion. **D**: Elbow extension.

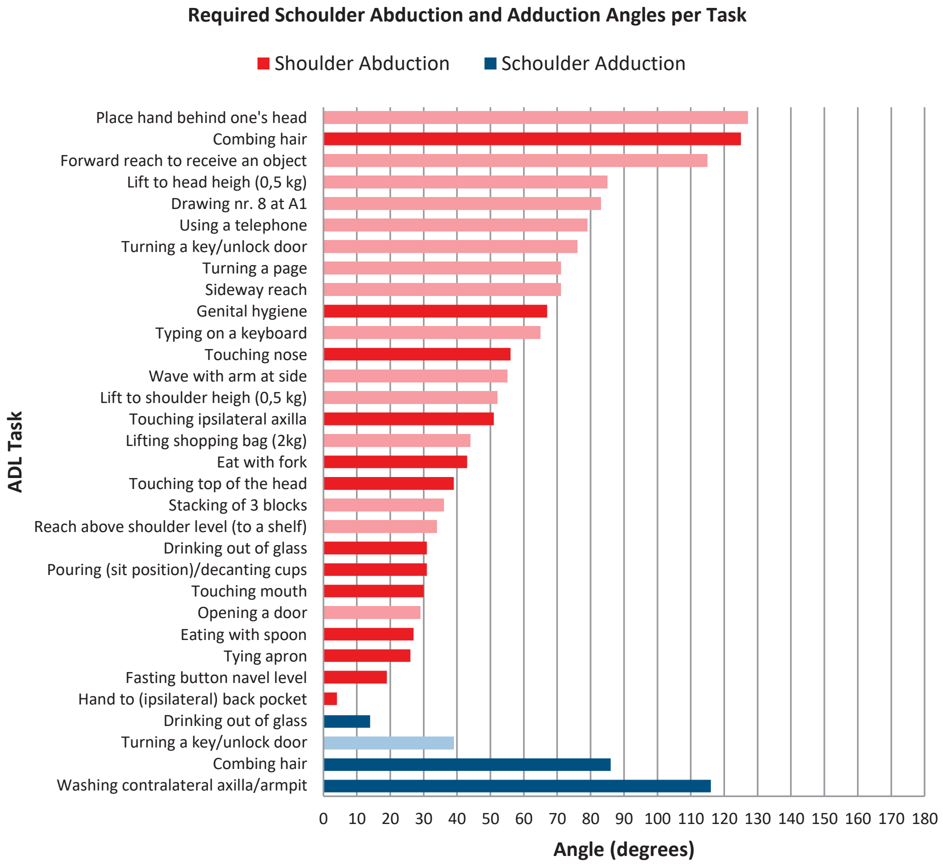

Figure 4(B) - *Continued.*

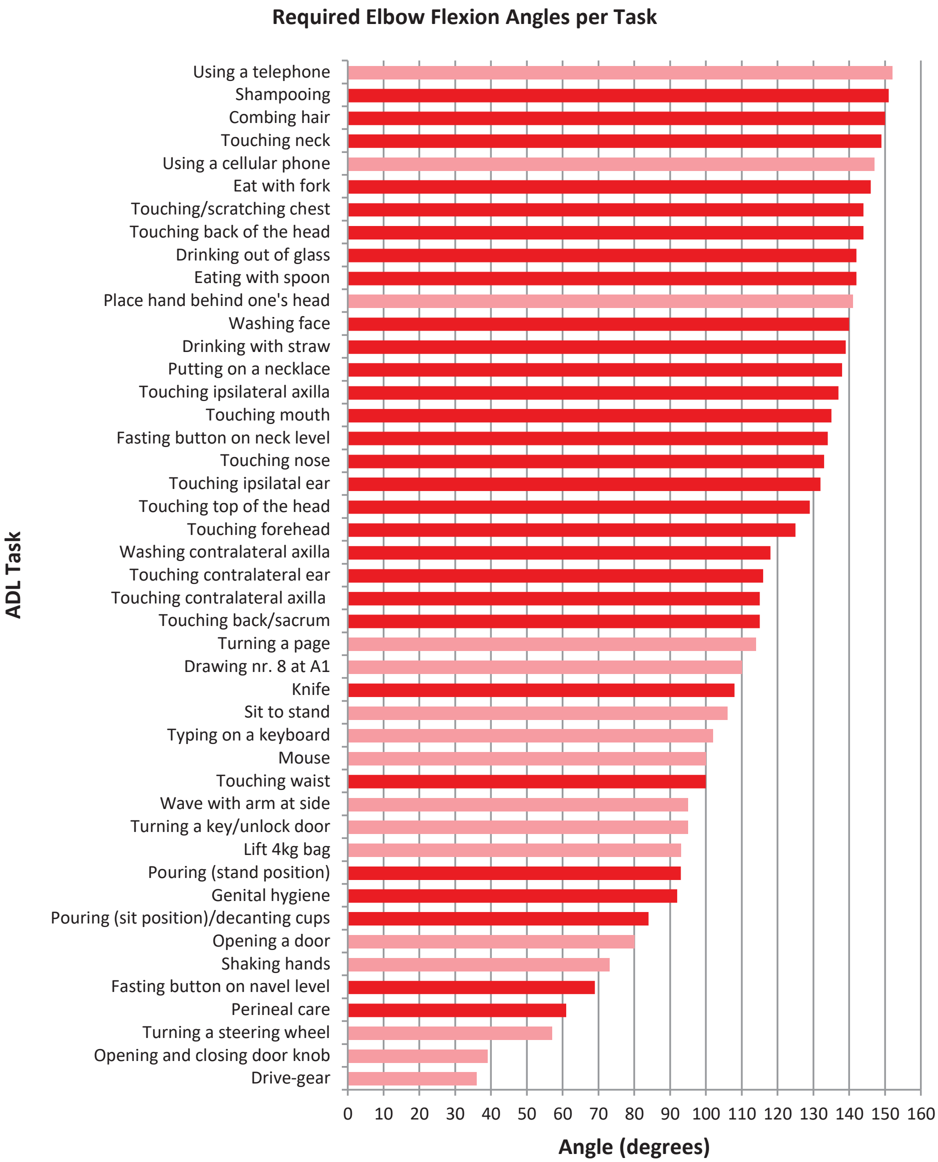

Figure 4(C) - *Continued.*

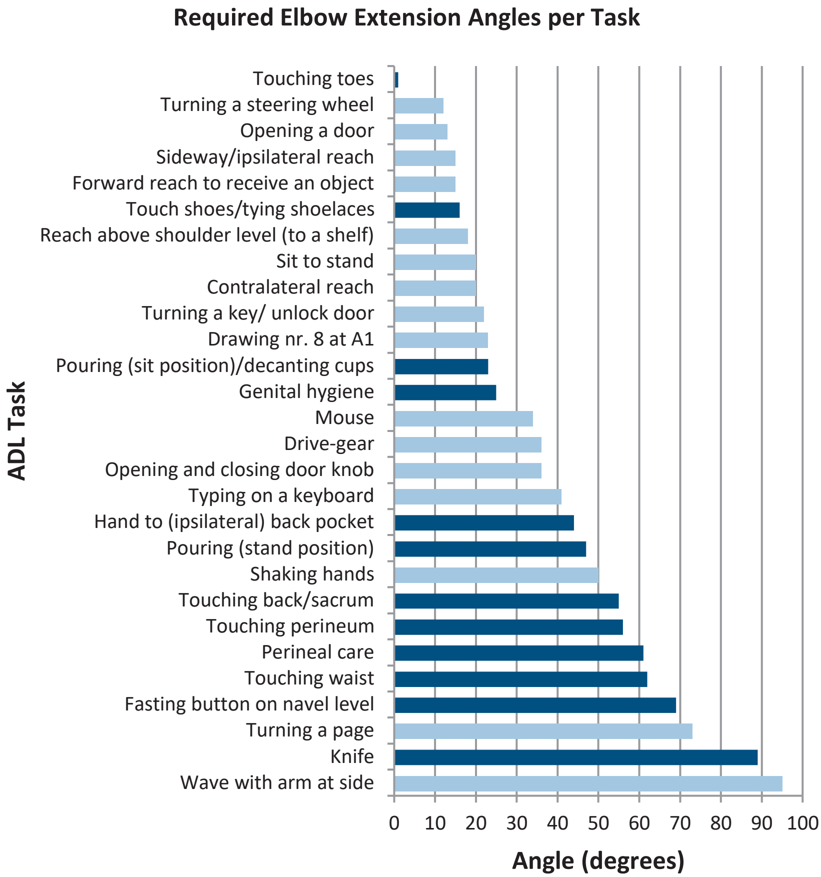

Figure 4(D) - *Continued.*

DISCUSSION

This systematic review presents the shoulder and elbow joint angles that are used by unimpaired participants to perform a total of 66 different ADL tasks and demonstrates that, in order to be able to perform ADL, full ROM is critical in the elbow but is less significant in the shoulder.

The results for elbow flexion clearly indicated that many ADL tasks required angles from 130° up to 150°. It should be noted that these maximal angles were needed in basic ADL tasks of personal care, for instance, hair care and washing the face as well as in eating or drinking. The finding of the necessity of full elbow flexion in personal care and feeding tasks is in accordance with the conclusion of Ramanathan et al.[60] and Klotz et al.[18] However, in those studies, the maximal angles per separate task were not reported. Maximal elbow extension was not often necessary, although angles of 0-20° were required for tasks such as reaching and touching one's own toe, which represents putting on shoes and socks. Therefore, from our function-oriented synthesis, it can be concluded that elbow motion from 0° to 150° is required for ADL which is more than the generally used reference of 30°-130°.[21] A comparison with the results concerning elbow motion presented in the function-oriented review of Korp et al.[22] in the context of burn contractures is severely impaired as only a minimal number of studies on elbow motion were included, and no overview of results per task was provided.

Results of the shoulder were different compared to the elbow as, in order to perform ADL tasks, full shoulder motion proved to only be necessary in some of the movement directions. For both shoulder flexion and abduction, unimpaired participants only used approximately 130° of the maximally possible 180°. The only reported exception was a shoulder flexion angle of 142° in reaching toward a high shelf. On the contrary, up to 62° shoulder extension, which is considered full ROM,[16] was found in tasks comprising personal care activities such as perineal hygiene and washing the lower back. Full shoulder adduction ROM was also needed in ADL, however, this movement direction was only minimally represented in the evaluated tasks. Korp et al.[22] concluded that upper limits of 150° and 90° were needed in ADL for shoulder flexion and abduction, respectively. However, both values referred to the study of Koch et al.,[61] and it was uncertain how these values were determined.

The selection of ADL tasks varied among studies. Several explicitly motivated their choice of tasks, referring to: function assessment scales or tests;[12,15,43,44,46,53,58,59] surveys of patient groups;[41,52] consultation with the clinical staff;[12,52] and/or on (some) task(s) selected in earlier studies or pilot testing.[37,43,45,49-51,56] Others did not justify their choices.

In the current review, all reported tasks were clustered into two categories (i.e., basic daily activities involving personal care and feeding, as well as other activities involving housework, communication, and transportation). Being able to perform basic daily activities is essential for independent living and should, therefore, receive special attention in research and also be a primary therapeutic aim. The use of more categories might be beneficial, however, deciding on how many and which categories would be optimal was beyond the scope of this study.

The results showed that, although the required angles during basic ADL were often measured, dressing tasks were not systematically studied. The possible reason for this is that angles are not detectable with 3D markers during dressing. Measurement systems independent of 3D markers can provide additional insight into dressing tasks as, for instance, 'putting on a coat' was shown to require large shoulder angles in community-dwelling seniors.[62] For other ADL tasks involving shoulder and elbow motion, more tasks could be included as well. For example, housekeeping was not measured at all. Transportation was examined solely by Anglin and Wyss,[63] however, these results could not be included in this review as only angles corresponding to the peak external moment were reported and not the angles needed to complete tasks. The development of an extensive list of basic ADL tasks and a list of ADL tasks based on a clinical perspective as well as from a patient perspective is strongly recommended.

In the present review, separate analyses were not feasible per age group, gender, or hand dominance of the participants. However, task execution can be influenced by these factors.[64] Regarding age, only one study[29] included adults and the elderly. Results indicated similar elbow flexion angles in both groups but lower shoulder flexion angles in the elderly. Unfortunately, the male-female ratio also differed significantly between the age groups thereby limiting conclusions based solely on age. Concerning gender, separate male and female groups were present in two studies[28,30] which concluded that differences between genders should be taken into account as the averaged movement performance differed during the tasks. Whether these differences could be attributed to gender alone was uncertain as both groups involved fewer than ten participants, no standard deviations per group were provided, and no statistical analyses were conducted. Regarding hand dominance, in four studies,[14,38-40] participants simultaneously performed tasks with both hands or in succession, however, none of the studies systematically compared the results. Therefore, although extensive attention is paid in the literature to age or gender differences regarding required shoulder and elbow ROM,[64-67] reliable information on differences in task execution is insufficient.

Limitations of the study

Although the results of the present review are noteworthy, caution is necessary when applying them to clinical practice. First, even though 66 ADL tasks were analyzed, still not all daily activities were assessed. Therefore, there may be tasks that require larger angles than those shown in this review.

Second, the synthesis of results focused on the maximal angle per task. This angle may not be representative for each individual during the execution of tasks due to postural variabilities and variations such as body or upper limb length. Hence, some individuals will need larger joint angles in ADL and some may be able to perform daily tasks with somewhat smaller angles compared to the average. Despite such individual variabilities, the conclusion remains that many personal care and feeding tasks require extensive elbow flexion.

Third, the methodological quality was not optimal for all of the included studies but, overall, a low to moderate ROB was determined. Therefore, it is not believed that this has had consequences for the overall outcome of this review.

Fourth, for tasks that were studied in more than one reviewed study group, it was decided to use the highest value for Figure 4A-D as it was opined that this maximal value gave an indication of the joint angle required to complete tasks in all potential movement patterns as measured by the different individual studies. However, it could be argued that this choice led to a skewing of the results. The possibility of a full synthesis with forest plots was discussed as well but, due to the limited available data (group means plus SD) per movement direction per task (Appendix 2A-F), this was not possible.

Finally, in the present review, all shoulder movement data were translated from ISB terms to terms of flexion, extension, abduction, and adduction as it was suggested that this yielded the most beneficial information for the physical and occupational therapy practice. Consequently, for daily activities in which the plane of elevation angle was approximately 45°, the movement direction of that specific task would change from flexion to abduction or vice versa if this angle was a few degrees less or more. For instance, a PoE of 46° for pouring water into a glass[43] was described as flexion but would be described as abduction if this angle was 44°. However, as it involved only a few tasks, there is confidence that this translation has not influenced the primary conclusions. In addition, it was initially planned to include shoulder rotation movements in this review, however, it became apparent that results would be incomparable due to the different methods used to analyze rotation. A number of studies employed the ISB axial rotation definition[26,27] while others used the definition of the non-singular axial rotation[68] or reported rotation data without mentioning the used method. Furthermore, the amount of humeral rotation needed to complete tasks depends on the position of the arm in space.[53] The current recommendation is that the method of 3D measuring for rotation must be described in detail in future research.

Future directions

First, for use in physical and occupational therapy practice, tables or figures with functional ROM should be developed per ADL category, age group, and eventually gender and hand dominance. Therefore, further research should focus on expanding the amount and diversity of tasks and being aware of the differences of the participant's characteristics. Second, additional research is required on how often and for how long especially large angles are used by unimpaired participants in ADL tasks during the day. As mentioned in the introduction, when functional ROM cannot be recovered, compensatory movements in other components of the coordinated joint system will be indispensable for accomplishing ADL tasks.[5,9,10,69] Such movements pose a risk for overuse problems. The magnitude of this risk depends on how often, for how long, and at which angle these compensatory movements are necessary during the day. Third, an impaired ROM cannot only hamper ADL but can also have an impact on patient's perceived (social) participation.[70,71] To optimize and tailor mobility interventions, more research is needed on the correlation between ROM impairment, functioning, participation, and quality of life. Furthermore, inclusion and evaluation of patient's goals of treatment is crucial.

IMPLICATIONS FOR PHYSIOTHERAPY PRACTICE

Shoulder and elbow angles needed to perform daily activities by unimpaired participants have been investigated in many well-performed studies. Full ROM was critical in the elbow to be able to perform ADL but was less important in the shoulder when performing 66 (simulated) tasks. These data should be used to assess impairments on the individual level and to establish goals in physical and occupational therapy both in terms of function and prevention of secondary conditions due to overuse of compensatory movements.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the article.

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REFERENCES

1. World Health Organization. International Classification of Functioning, Disability and Health (ICF). 2001.
2. Pieniazek M, Chwala W, Szczechowicz J, Pelczar-Pieniazek M. Upper limb joint mobility ranges during activities of daily living determined by three-dimensional motion analysis - preliminary report. Ortop Traumatol Rehabil. 2007;9:413-22.
3. Adams BD, Grosland NM, Murphy DM, McCullough M. Impact of impaired wrist motion on hand and upper-extremity performance. J Hand Surg Am. 2003;28:898-903.
4. Bland MD, Beebe JA, Hardwick DD, Lang CE. Restricted active range of motion at the elbow, forearm, wrist, or fingers decreases hand function. J Hand Ther. 2008;21:268-74.
5. de Groot JH, Angulo SM, Meskers CG, van der Heijden-Maessen HC, Arendzen JH. Reduced elbow mobility affects the flexion or extension domain in activities of daily living. Clin Biomech (Bristol, Avon). 2011;26:713-7.
6. Pereira BP, Thambyah A, Lee T. Limited forearm motion compensated by thoracohumeral kinematics when performing tasks requiring pronation and supination. J Appl Biomech. 2012;28:127-38.
7. Metzger AJ, Dromerick AW, Holley RJ, Lum PS. Characterization of compensatory trunk movements during prosthetic upper limb reaching tasks. Arch Phys Med Rehabil. 2012;93:2029-34.
8. Fradet L, Liefhold B, Rettig O, Bruckner T, Akbar M, Wolf SI. Proposition of a protocol to evaluate upper-extremity functional deficits and compensation mechanisms: application to elbow contracture. J Orthop Sci. 2015;20:321-30.
9. Mell AG, Childress BL, Hughes RE. The effect of wearing a wrist splint on shoulder kinematics during object manipulation. Arch Phys Med and Rehabil. 2005;86:1661-4.
10. Veeger HE, Magermans DJ, Nagels J, Chadwick EK, van der Helm FC. A kinematical analysis of the shoulder after arthroplasty during a hair combing task. Clin Biomech (Bristol, Avon). 2006;21(Suppl 1):S39-44.
11. Willig TN, Bach JR, Rouffet MJ, Krivickas LS, Maquet C. Correlation of flexion contractures with upper extremity function and pain for spinal muscular atrophy and congenital myopathy patients. Am J Phys Med Rehabil. 1995;74:33-8.
12. Magermans DJ, Chadwick EK, Veeger HE, van der Helm FC. Requirements for upper extremity motions during activities of daily living. Clin Biomech (Bristol, Avon). 2005;20:591-9.
13. Fergusson D, Hutton B, Drodge A. The epidemiology of major joint contractures: a systematic review of the literature. Clin Orthop Relat Res. 2007;456:22-9.
14. Petuskey K, Bagley A, Abdala E, James MA, Rab G. Upper extremity kinematics during functional activities: three-dimensional studies in a normal pediatric population. Gait Posture. 2007;25:573-9.
15. van Andel CJ, Wolterbeek N, Doorenbosch CA, Veeger DH, Harlaar J. Complete 3D kinematics of upper extremity functional tasks. Gait Posture. 2008;27:120-7.
16. Magee DJ. Orthopedic physical assessment. 5th ed St Louis, Saunders Elsevier; 2008.
17. Skalsky AJ, McDonald CM. Prevention and management of limb contractures in neuromuscular diseases. Phys Med Rehabil Clin N Am. 2012;23:675-87.
18. Klotz MC, Kost L, Braatz F, Ewerbeck V, Heitzmann D, Gantz S, Dreher T, Wolf SI. Motion capture of the upper extremity during activities of daily living in

patients with spastic hemiplegic cerebral palsy. Gait Posture. 2013;38:148-52.
19. Kim K, Park DS, Ko BW, Lee J, Yang SN, Kim J, Song WK. Arm motion analysis of stroke patients in activities of daily living tasks: a preliminary study. Conf Proc: IEEE Eng Med and Biol Soc. 2011;2011:1287-91.
20. Kasten P, Maier M, Wendy P, Rettig O, Raiss P, Wolf S, Loew M. Can shoulder arthroplasty restore the range of motion in activities of daily living? A prospective 3D video motion analysis study. J Shoulder Elbow Surg. 2010;19:59-65.
21. Morrey BF, Askew LJ, Chao EY. A biomechanical study of normal functional elbow motion. J Bone Joint Surg Am. 1981;63:872-7.
22. Korp K, Richard R, Hawkins D. Refining the idiom "functional range of motion" related to burn recovery. J Burn Care Res. 2015;36:e136-45.
23. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Reprint-preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Phys Ther. 2009;89:873-80.
24. Sanderson S, Tatt ID, Higgins JP. Tools for assessing quality and susceptibility to bias in observational studies in epidemiology: a systematic review and annotated bibliography. Int J Epidemiol. 2007;36:666-76.
25. Zeng X, Zhang Y, Kwong JS, Zhang C, Li S, Sun F, Niu Y, Du L. The methodological quality assessment tools for preclinical and clinical studies, systematic review and meta-analysis, and clinical practice guideline: a systematic review. J Evid Based Med. 2015;8:2-10.
26. Doorenbosch CA, Harlaar J, Veeger DH. The globe system: an unambiguous description of shoulder positions in daily life movements. J Rehabil Res Dev. 2003;40:147-55.
27. Wu G, van der Helm FC, Veeger HE, Makhsous M, Van Roy P, Anglin C, Nagels J, Karduna AR, McQuade K, Wang X, Werner FW, Buchholz B; International Society of Biomechanics. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion - part II: shoulder, elbow, wrist and hand. J Biom. 2005;38:981-92.
28. Cooper JE, Shwedyk E, Quanbury AO, Miller J, Hildebrand D. Elbow joint restriction: effect on functional upper limb motion during performance of three feeding activities. Arch Phys Med Rehabil. 1993;74:805-9.
29. Lee JH, Chun MH, Jang DH, Ahn JS, Yoo JY. A comparison of young and old using three-dimensional motion analyses of gait, sit-to-stand and upper extremity performance. Aging Clin Exp Res. 2007;19:451-6.
30. Müller-Rath R, Disselhorst-Klug C, Williams S, Braun C, Miltner O. Influence of sex and side dominance on the results of quantitative, three-dimensional motion analysis of the upper extremities. Z Orthop Unfall. 2009;147:463-71.
31. Raiss P, Rettig O, Wolf S, Loew M, Kasten P. Range of motion of shoulder and elbow in activities of daily life in 3D motion analysis. Z Orthop Unfall. 2007;145:493-98.
32. Kasten P, Rettig O, Loew M, Wolf S, Raiss P. Three-dimensional motion analysis of compensatory movements in patients with radioulnar synostosis performing activities of daily living. J Orthop Sci. 2009;14:307-12.
33. Raiss P, Maier MW, Wolf SI, Rettig O, Loew M, Kasten P. 3D motion analysis of the upper extremities and its application in shoulder arthroplasty. Obere Extrem. 2010;5:27-36.
34. Maier MW, Kasten P, Niklasch M, Dreher T, Zeifang F, Rettig O, Wolf SI. 3D motion capture using the HUX model for monitoring functional changes with arthroplasty in patients with degenerative

osteoarthritis. Gait Posture. 2014a;39:7-11.
35. Maier MW, Niklasch M, Dreher T, Zeifang F, Rettig O, Klotz MC, Wolf SI, Kasten P. Motion patterns in activities of daily living: 3-year longitudinal follow-up after total shoulder arthroplasty using an optical 3D motion analysis system. BMC Musculoskelet Disord. 2014b;15:244.
36. Safaee-Rad R, Shwedyk E, Quanbury AO, Cooper JE. Normal functional range of motion of upper limb joints during performance of three feeding activities. Arch Phys Med Rehabil. 1990;71:505-9.
37. King S, Thomas JJ, Rice MS. The immediate and short-term effects of a wrist extension orthosis on upper-extremity kinematics and range of shoulder motion. Am J Occup Ther. 2003;57:517-24.
38. Palmieri TL, Petuskey K, Bagley A, Takashiba S, Greenhalgh DG, Rab GT. Alterations in functional movement after axillary burn scar contracture: a motion analysis study. J Burn Care Rehabil. 2003;24:104-8.
39. Mosqueda T, James MA, Petuskey K, Bagley A, Abdala E, Rab G. Kinematic assessment of the upper extremity in brachial plexus birth palsy. J Pediatr Orthop. 2004;24:695-9.
40. Henmi S, Yonenobu K, Masatomi T, Oda K. A biomechanical study of activities of daily living using neck and upper limbs with an optical three-dimensional motion analysis system. Mod Rheumatol. 2006;16:289-93.
41. Carey SL, Jason Highsmith M, Maitland ME, Dubey RV. Compensatory movements of transradial prosthesis users during common tasks. Clin Biomech (Bristol, Avon). 2008;23:1128-35.
42. Sheikzadeh A, Yoon J, Pinto VJ, Kwon YW. Three-dimensional motion of the scapula and shoulder during activities of daily living. J Shoulder Elbow Surg. 2008;17:936-42.
43. Aizawa J, Masuda T, Koyama T, Nakamaru K, Isozaki K, Okawa A, Morita S. Three-dimensional motion of the upper extremity joints during various activities of daily living. J Biomech. 2010;43:2915-22.
44. Murgia A, Kyberd P, Barnhill T. The use of kinematic and parametric information to highlight lack of movement and compensation in the upper extremities during activities of daily living. Gait Posture. 2010;31:300-6.
45. Ramírez-García A, Leija L, Muñoz R. Active upper limb prosthesis based on natural movement trajectories. Prosthet Orthot Int. 2010;34:58-72.
46. Reid S, Elliott C, Alderson J, Lloyd D, Elliott B. Repeatability of upper limb kinematics for children with and without cerebral palsy. Gait Posture. 2010;32:10-7.
47. Sinha A, Nazar MA, Moorehead J, Bhalaik V, Brownson P. A kinematic assessment of normal elbow movement in activities of modern day living. Shoulder Elbow. 2010;2:118-23.
48. Hall LC, Middlebrook EE, Dickerson CR. Analysis of the influence of rotator cuff impingements on upper limb kinematics in an elderly population during activities of daily living. Clin Biomech (Bristol, Avon). 2011;26:579-84.
49. Masjedi M, Lovell C, Johnson GR. Comparison of range of motion and function of subjects with reverse anatomy Bayley-Walker shoulder replacement with those of normal subjects. Hum Mov Sci. 2011;30:1062-71.
50. Murphy MA, Willén C, Sunnerhagen KS. Kinematic variables quantifying upper-extremity performance after stroke during reaching and drinking from a glass. Neurorehabil Neural Repair. 2011;25:71-80.
51. Sardelli M, Tashjian RZ, MacWilliams BA. Functional elbow range of motion for

contemporary tasks. J Bone Joint Surg Am. 2011;93:471-7.

52. Karner J, Reichenfelser W, Gfoehler. Kinematic and kinetic analysis of human motion as design input for an upper extremity bracing system. Biomed Eng. 2012;376-83.
53. Namdari S, Yagnik G, Ebaugh DD, Nagda S, Ramsey ML, Williams GR Jr, Mehta S. Defining functional shoulder range of motion for activities of daily living. J Shoulder Elbow Surg. 2012;21:1177-83.
54. Artilheiro MC, Corrêa JC, Cimolin V, Lima MO, Galli M, de Godoy W, Lucareli PR. Three-dimensional analysis of performance of an upper limb functional task among adults with dyskinetic cerebral palsy. Gait Posture. 2014;39:875-81.
55. Bergsma A, Murgia A, Cup EH, Verstegen PP, Meijer K, de Groot IJ. Upper extremity kinematics and muscle activation patterns in subjects with facioscapulohumeral dystrophy. Arch Phys Med Rehabil. 2014;95:1731-41.
56. Kim K, Song WK, Lee J, Lee HY, Park DS, Ko BW, Kim J. Kinematic analysis of upper extremity movement during drinking in hemiplegic subjects. Clin Biomech (Bristol, Avon). 2014;29:248-56.
57. Klotz MC, van Drongelen S, Rettig O, Wenger P, Gantz S, Dreher T, Wolf SI. Motion analysis of the upper extremity in children with unilateral cerebral palsy - an assessment of six daily tasks. Res Dev Disabil. 2014;35:2950-7.
58. Lobo-Prat J, Font-Llagunes JM, Gómez-Pérez C, Medina-Casanovas J, Angulo-Barroso RM. New biomechanical model for clinical evaluation of the upper extremity motion in subjects with neurological disorders: an application case. Comput Methods Biomech Biomed Engin. 2014;17:1144-56.
59. Major MJ, Stine RL, Heckathorne CW, Fatone S, Gart SA. Comparison of range-of-motion and variability in upper body movements between transradial prosthesis users and able-bodied controls when executing goal-oriented tasks. J Neuroeng Rehabil. 2014;11:132.
60. Ramanathan R, Eberhardt SP, Rahman T, Sample W, Seliktar R, Alexander M. Analysis of arm trajectories of everyday tasks for the development of an upper-limb orthosis. IEEE Trans Rehabil Eng. 2000;8:60-70.
61. Koch M, Gottschalk M, Baker DI, Palumbo S, Tinetti ME. An impairment and disability assessment and treatment protocol for community-living elderly persons. Phys Ther. 1994;74:286-298.
62. Green SL, Boger JN, Mihailidis A. Toward enabling winter occupations: testing a winter coat designed for older adults. Can J Occup Ther. 2011;78:57-64.
63. Anglin C, Wyss UP. Arm motion and load analysis of sit-to-stand, stand-to-sit, cane walking and lifting. Clin Biomech (Bristol, Avon). 2000;15:441-8.
64. Barnes CJ, Van Steyn SJ, Fischer RA. The effects of age, sex, and shoulder dominance on range of motion of the shoulder. J Shoulder Elbow Surg. 2001;10:242-6.
65. Doriot N, Wang X. Effects of age and gender on maximum voluntary range of motion of the upper body joints. Ergonomics. 2006;49: 269-81.
66. Medeiros HB, de Araújo DS, de Araújo CG. Age-related mobility loss is joint-specific: an analysis from 6,000 Flexitest results. Age (Dordr). 2013;35: 2399-407.
67. Stathokostas L, McDonald MW, Little RM, Paterson DH. Flexibility of older adults aged 55-86 years and the influence of physical activity. J Aging Res. 2013;2013:743843.
68. Masuda T, Ishida A, Cao L, Morita S. A proposal for a new definition of the axial rotation angle of the shoulder joint. J Electromyogr Kinesiol. 2008;18:154-9.
69. Trehan SK, Wolff AL, Gibbons M, Hillstrom HJ, Daluiski A. The effect of simulated

elbow contracture on temporal and distance gait parameters. Gait Posture. 2015;41:791-4.
70. Fischer U, Bartoszek G, Müller M, Strobl R, Meyer G, Grill E. Patients' view on health-related aspects of functioning and disability of joint contractures: a qualitative interview study based on the International Classification of Functioning, Disability and Health (ICF). Disabil Rehabil. 2014;36:2225-32.
71. Bartoszek G, Fischer U, Grill E, Müller M, Nadolny S, Meyer G. Impact of joint contracture on older persons in a geriatric setting: a cross-sectional study. Z Gerontol Geriatr. 2015;48:625-3

Appendix 1 - MeSH terms and number of retrieved studies per database.

PubMed:
Search: *("upper extremity"[MeSH Terms] OR "elbow"[Title] OR "shoulder"[Title]) AND ("range of motion"[MeSH Terms] OR "motion"[Title] OR "range of motion"[Title/abstract]) AND ("activities of daily living"[MeSH Terms] OR "activities of daily living"[Title/Abstract])*.
Search resulted in 273 studies.

Cochrane:
Advanced search on title, abstract and keywords: *Range of motion AND (activities of daily living) OR (daily activities) OR (daily living) AND (upper extremity) OR (elbow) OR (shoulder)*.
Search resulted in 100 studies.

Scopus:
Search: *TITLE-ABS-KEY ('Activities of Daily Living' AND 'Range of Motion' AND 'Upper Extremity').*
Search resulted in 241 studies.

CINAHL:
Advanced search on: *'Activities of Daily Living' AND 'Range of Motion' AND 'Upper Extremity'* without selecting a field.
Search resulted in 58 studies.

PEDro:
Simple search on: *'activities of daily living, range of motion'*.
Search resulted in 44 studies.

Appendix 2A-F - Shoulder and elbow angles (degrees) per (simulated) ADL tasks used by unimpaired participants for **A**: shoulder flexion, **B**: shoulder extension, **C**: shoulder abduction, **D**: shoulder adduction, **E**: elbow flexion, **F**: elbow extension.

Appendix 2A - Shoulder flexion angles (degrees) per (simulated) ADL task used by unimpaired participants.

	Required angle	Aizawa et al (2010)	Artilheiro et al (2014)	Carey et al (2008)	Cooper et al (1993) Female	Cooper et al (1993) Male	Hall et al (2011)	Henmi et al (2006)	Karner et al (2012)	Kim et al (2014)	King et al (2003)	Klotz et al (2014)	Lee et al (2007) Adult
Personal care and feeding													
Combing hair	**139**	110 (14)					70		56				
Brush contralateral side of the head	**61**												
Shampooing	**64**							64 (9)					
Washing face	**50**	44 (10)						50 (7)					
Putting on a necklace	**106**	106 (19)											
Fasting button neck level	**29**	29 (11)											
Washing contralateral axilla/armpit	**95**						18						
Genital hygiene	**84**												
Touching top of the head	**105**												68 (26)
Touching forehead	**64**	59 (10)											
Touching contralateral ear	**64**	64 (11)											
Touching ipsilatal ear	**70**	70 (12)											
Touching nose	**77**											77	
Touching chin	**38**												
Touching back of the head	**110**												
Touching neck	**124**												
Touching contralateral axilla	**57**	42 (13)											
Touching/scratching chest	**34**								34				
Eat with fork	**35**				29	28							
Eating with spoon	**78**	56 (11)			31	31						67	
Pouring (sit position)/decanting cups	**72**										60	68	
Pouring (stand position)	**64**	64 (20)											
Drinking out of glass	**87**	87 (12)	71†	70	31	36				86 (5)		86	
Drinking with straw	**33**								33				
Touching mouth	**65**	40 (10)											65 (35)

Lee et al (2007) Elderly	Lobo-Prat et al (2014)	Maier et al (2014a), Maier et al (2014b)	Major et al. (2014)	Masjedi et al (2011)	Mosqueda et al (2004)	Muller-Rath et al (2009) Female	Muller-Rath et al (2009) Male	Muragia et al (2010)	Murphy et al (2013)	Namdari et al (2012)	Palmieri et al (2003)	Petuskey et al (2007)	Raiss et al (2007), Kasten et al (2009), Raiss et al (2010)	Reid et al (2010)	Safaee-Rad (1990)	Sheikhzadeh et al (2008) *	van Andel et al (2008)
		139								108 (3)			78 ‡				
				61													
		75								95 (2)							
													84 ‡				
43 (19)					83 (14)							85 (17)				105 (9)	
																64 (7)	
																62 (3)	
																65 (5)	
																38 (4)	
																110 (10)	
																124 (13)	
				44												54 (9)	57
															35 (12)		
													78		36 (14)		
			67	57									72				
				31													
				38					52 (5)				87		43 (16)		63
35 (10)														38			

Appendix 2A - Shoulder flexion angles (degrees) per (simulated) ADL task used by unimpaired participants. (*continued*)

	Required angle	Aizawa et al (2010)	Artilheiro et al (2014)	Carey et al (2008)	Cooper et al (1993) Female	Cooper et al (1993) Male	Hall et al (2011)	Henmi et al (2006)	Karner et al (2012)	Kim et al (2014)	King et al (2003)	Klotz et al (2014)	Lee et al (2007) Adult
Daily, leasure and work activities													
Reach above shoulder level (to a shelf)	**142**												
Reach at 1.5m of the ground	**82**						82						
Forward reach to receive an object	**80**						75						63 (14) §
Sideway reach	**56**												
Place hand behind one's head	**130**												
Using a telephone	**85**												
Turning a key/unlock door	**114**											83	
Turning a page	**96**												
Opening a door	**52**			52 (12)									
Wave with arm at side	**48**												
Drawing nr. 8 at A1	**79**												
Stacking of 3 blocks	**58**										58		
Lifting tray using both hands (0.5kg)	**48**												
Typing on a keyboard	**93**												
Needed range	**29-142**												

*: data changed to positive values; †: at going phase mug to mouth; ‡: not reported in Kasten et al (2009);
§: reaching at shoulder height; ||: reaching at table height; #: calculated out of dataset.

Lee et al (2007) Elderly	Lobo-Prat et al (2014)	Maier et al (2014a), Maier et al (2014b)	Major et al. (2014)	Masjedi et al (2011)	Mosqueda et al (2004)	Muller-Rath et al (2009) Female	Muller-Rath et al (2009) Male	Muragia et al (2010)	Murphy et al (2013)	Namdari et al (2012)	Palmieri et al (2003)	Petuskey et al (2007)	Raiss et al (2007), Kasten et al (2009), Raiss et al (2010)	Reid et al (2010)	Safaee-Rad (1990)	Sheikhzadeh et al (2008) *	van Andel et al (2008)
		132			139 (11)					121 (2)	134 (28)	142 (10)					
47 (10) §	59 §			80								32 (17)		66 ||			
						20 §	56 §							28 §			
						130	130										
				45									85				
													114				
								42					96				
												48 (27)					
													79				
				48													
													93				

Appendix 2B - Required shoulder extension angles (degrees) per (simulated) ADL tasks performed by unimpaired participants.

	Required angle	Aizawa et al (2010)	Hall et al (2011)	Maier et al (2014a) Maier et al (2014b)	Masjedi et al (2011)	Mosqueda et al (2004)	Namdari et al (2012)	Palmieri et al (2003)	Petuskey et al (2007)	Raiss et al (2007), Kasten et al (2009), Raiss et al (2010)	van Andel et al (2008)
Personal care and feeding											
Unhook bra/wash middle of back	**47**						47 (2)				
Tuck in shirt behind back	**46**						46 (2)				
Tying apron	**44**			44							
Wash lower back	**62**				62						
Perineal care	**44**		44								
Anal hygiene	**13**									13 *	
Hand to (ipsilateral) back pocket	**50**					49 (8)		50 (8)	47 (11)		48
Touching back/sacrum	**52**	52 (12)									
Touching perineum	**41**	41 (8)									
Eating with spoon	**12**									12	
Daily, leasure and work activities											
Using a telephone	**3**									3	
Needed range	**3 - 62**										

*: not reported in Kasten et al (2009).

Appendix 2C - Required shoulder abduction angles (degrees) per (simulated) ADL tasks performed by unimpaired participants.

	Required angle	Aizawa et al (2010)	Carey et al (2008)	Cooper et al (1993) Female	Cooper et al (1993) Male	Hall et al (2011)	Henmi et al (2006)	Kim et al (2014)	King et al (2003)
Personal care and feeding									
Combing hair	**125**								
Fasting button navel level	**19**	19 (6)							
Tying apron	**26**								
Genital hygiene	**67**								
Hand to (ipsilateral) back pocket	**4**								
Touching top of the head	**39**								
Touching nose	**56**								
Touching ipsilateral axilla	**51**	51 (18)							
Eat with fork	**43**			23	17		43 (6)		
Eating with spoon	**27**			27	17	24			
Pouring (sit position)/decanting cups	**31**								31
Drinking out of glass	**31**		28	28	23			12 (4)	
Touching mouth	**30**								
Daily, leasure and work activities									
Reach above shoulder level (to a shelf)	**34**								
Forward reach to receive an object	**115**								
Sideway reach	**71**								
Place hand behind one's head	**127**								
Using a telephone	**79**								
Turning a key/unlock door	**76**								
Turning a page	**71**								
Opening a door	**29**		29 (7)						
Wave with arm at side	**55**								
Drawing nr. 8 at A1	**83**								
Stacking of 3 blocks	**36**								36
Lifting shopping bag (2kg)	**44**								
Lift to shoulder heigh (0,5 kg)	**52**								
Lift to head heigh (0,5 kg)	**85**								
Typing on a keyboard	**65**								
Needed range	**4 - 127**								

*: not reported in Kasten et al (2009); †: reaching at shoulder height; ‡: reaching at table height; §: left out for further analysis; ||: taking book from shelf.

	Klotz et al (2014)	Maier et al (2014a), Maier et al (2014b)	Major et al (2014)	Masjedi et al (2011)	Mosqueda et al (2004)	Muller-Rath et al (2009) Female	Muller-Rath et al (2009) Male	Murphy et al (2011)	Namdari et al (2012)	Palmieri et al (2003)	Petuskey et al (2007)	Raiss et al (2007), Kasten et al (2009), Raiss et al (2010)	Reid et al (2010)	Safaee-Rad (1990)	van Andel et al (2008)
		74										125 *			100
		26													
												67 *			
					4 (8)					4 (8)	2 (5)				
					39 (13)						36 (13)				
	56														
														19(6)	
	65 §											107 §		22(7)	
	50 §		30									86 §			
	77 §							30 (10)				111 §		31 (9)	
													30		
					32 (11)					32 (12)	34 (9)				
		115 ‖									5 (10)		49 ‡		
						68 †	68 †						71 †		
						51	46		127 (2)						
												79			
	56											76			
												71			
											55 (10)				
												83			
				44											
				52											
				85											
												65			

Appendix 2D - Required shoulder adduction angles (degrees) per (simulated) ADL tasks performed by unimpaired participants.

	Required angle	Artilheiro et al (2014)	Klotz et al (2014)	Maier et al (2014a), Maier et al (2014b)	Namdari et al (2012)
Personal care and feeding					
Combing hair	**86**				86 (3)
Washing contralateral axilla/armpit	**116**			37	116 (2)
Drinking out of glass	**14**	14 *			
Daily, leasure and work activities					
Turning a key/unlock door	**39**		39		
Needed range	**14-116**				

*: at going phase mug to mouth.

Appendix 2E - Required elbow flexion angles (degrees) per (simulated) ADL tasks performed by unimpaired participants.

	Required angle	Aizawa et al (2010)	Artilheiro et al (2014)	Carey et al (2008)	Cooper et al (1993) Female	Cooper et al (1993) Male	Henmi et al (2006)	Karner et al (2012)	Kim et al (2014)	Klotz et al (2014)	Lee et al (2007) Adult
Personal care and feeding											
Combing hair	**150**	119 (8)						141			
Shampooing	**151**						151 (9)				
Washing face	**140**	128 (6)					140 (5)				
Putting on a necklace	**138**	138 (6)									
Fasting button on neck level	**134**	134 (7)									
Fasting button on navel level	**69**	69 (19)									
Washing contralateral axilla	**118**										
Perineal care	**61**										
Genital hygiene	**92**										
Touching top of the head	**129**										121 (22)
Touching forehead	**125**	124 (7)									
Touching contralateral ear	**116**	116 (8)									
Touching ipsilatal ear	**132**	132 (5)									
Touching back of the head	**144**										
Touching nose	**133**									133	
Touching neck	**149**										
Touching/scratching chest	**144**							132			
Touching back/sacrum	**115**	115 (9)									
Touching waist	**100**										
Touching ipsilateral axilla	**137**	137 (7)									
Touching contralateral axilla	**115**	100 (10)									
Eat with fork	**146**				122	114	146 (5)				
Eating with spoon	**142**	123 (8)			126	116				125	
Knife	**108**										
Pouring (sit position)/ decanting cups	**84**									79	
Pouring (stand position)	**93**	93 (7)									
Drinking out of glass	**142**	115 (5)	135 *	123	136	126			120 (4)	129	
Drinking with straw	**139**							139			
Touching mouth	**135**	130 (5)									103 (41)

Lee et al (2007) Elderly	Magermans et al (2005)	Major et al (2014)	Morrey et al (1981)	Mosqueda et al (2004)	Muller-Rath et al (2009) Female	Muller-Rath et al (2009) Male	Murgia et al (2010)	Petuskey et al (2007)	Raiss et al (2007), Kasten et al (2009), Raiss et al (2010)	Raminez-Garcia et al (2010)	Reid et al (2010)	Safaee-Rad (1990)	Sardelli et al (2011)	Sinha et al (2010)	van Andel et al (2008)
	136 (15)								150						122
	118 (9) †														
	61 (20)														
									92						
129 (2)			119 (6)	110 (9)				110 (7)					117	114 (20)	
														125 (19)	
			144 (7)										143 (6)	137 (17)	
			135 (5)										149 (5)	147 (18)	
			120 (8)										144 (5)	139 (24)	
			100 (13)											62 (15)	
															115
			128									122 (4)	128	110	
	132 (8)								142			123 (5)			
			107										108		
		111‡	58						68				84	62	
										76 (10)					
			130						142	135 (3)		129 (3)	131		126
130 (0)											135			132 (15)	

Appendix 2E - Required elbow flexion angles (degrees) per (simulated) ADL tasks performed by unimpaired participants. (*continued*)

	Required angle	Aizawa et al (2010)	Artilheiro et al (2014)	Carey et al (2008)	Cooper et al (1993) Female	Cooper et al (1993) Male	Henmi et al (2006)	Karner et al (2012)	Kim et al (2014)	Klotz et al (2014)	Lee et al (2007) Adult
Daily, leasure and work activities											
Place hand behind one's head	**141**										
Using a telephone	**152**										
Using a cellular phone	**147**										
Opening a door	**80**			66 (14)							
Opening and closing door knob	**39**										
Turning a key/unlock door	**95**										
Sit to stand	**106**										
Turning a page	**114**										
Drive-gear	**36**										
Turning a steering wheel	**57**			40							
Shaking hands	**73**										
Wave with arm at side	**95**										
Drawing nr. 8 at A1	**110**										
Lift 4kg bag	**93**										
Mouse	**100**										
Typing on a keyboard	**102**										
Needed range	**36 - 152**										

*: at going phase mug to mouth; †: performed by 16/24 participants; ‡: left out for further analysis.

Lee et al (2007) Elderly	Magermans et al (2005)	Major et al (2014)	Morrey et al (1981)	Mosqueda et al (2004)	Muller-Rath et al (2009) Female	Muller-Rath et al (2009) Male	Murgia et al (2010)	Petuskey et al (2007)	Raiss et al (2007), Kasten et al (2009), Raiss et al (2010)	Raminez-Garcia et al (2010)	Reid et al (2010)	Safaee-Rad (1990)	Sardelli et al (2011)	Sinha et al (2010)	van Andel et al (2008)
					141	139									
			136						152	144 (4)			146 (3)	136	
													147 (3)		
			57							80 (23)			63		
														39	
									95						
			95										106		
			104				96		94				114	81	
														36 (25)	
														57	
										73 (12)					
								95 (16)							
									110						
	93 (24)														
													100	34 (15)	
									102				102	41 (15)	

Appendix 2F - Required elbow extension angles (degrees) per (simulated) ADL tasks performed by unimpaired participants.

	Required angle	Aizawa et al (2010)	Bergsma et al (2014)	Carey et al (2008)	Klotz et al (2014)	Lee et al (2007) Adult	Lee et al (2007) Elderly	Lobo-Prat et al (2014)	Magermans et al (2005)
Personal care and feeding									
Fasting button on navel level	**69**	69 (19)							
Perineal care	**61**								61 (20)
Genital hygiene	**25**								
Hand to (ipsilateral) back pocket	**44**								
Touch shoes/tying shoelaces	**16**								
Touching waist	**62**								
Touching back/sacrum	**55**								
Touching perineum	**56**	56 (22)							
Touching toes	**1**								
Knife	**89**								
Pouring (sit position)/decanting cups	**23**				74				
Pouring (stand position)	**47**	93 (7)							
Daily, leasure and work activities									
Reach above shoulder level (to a shelf)	**18**								39 (18) *
Forward reach to receive an object	**15**					16 (10) †	15 (9) †	59 †	
Sideway/ipsilateral reach	**15**		24						
Contralateral reach	**20**		20						
Opening a door	**13**			13					
Opening and closing door knob	**36**								
Turning a key/unlock door	**22**				36				
Sit to stand	**20**								
Turning a page	**73**								
Drive-gear	**36**								
Turning a steering wheel	**12**			12					
Shaking hands	**50**								
Wave with arm at side	**95**								
Drawing nr. 8 at A1	**23**								
Mouse	**34**								
Typing on a keyboard	**41**								
Needed range	**1-95**								

*: performed by 8/24 participants; †: reaching at schoulder height; ‡: reaching at table height; §: left out for further analysis.

	Morrey et al (1981)	Mosqueda et al (2004)	Muller-Rath et al (2009) Female	Muller-Rath et al (2009) Male	Murgia et al (2010)	Palmieri et al (2003)	Petuskey et al (2007)	Raiss et al (2007), Kasten et al (2009), Raiss et al (2010)	Raminez-Garcia et al (2010)	Reid et al (2010)	Sardelli et al (2011)	Sinha et al (2010)	van Andel et al (2008)
								25					
		66 (17)				66 (19)	63 (21)						44
	16 (6)										27 (7)		
	100 (13)											62 (15)	
	70 (12)										102	55 (23)	
												1 (11)	
	89										99		
	36							23			68	27	
									47				
		22 (8)				23 (10)	18 (6)						
							49 (25)			21 ‡			
			26 †	26 †						15 †			
	24								28		29		
												36	
								22					
	20										24		
	78				84			20 §			86	73	
												36 (25)	
												24	
									50				
							95 (16)						
								23					
											67	34 (15)	
								41			87	41 (15)	

3

4

Rating scales for shoulder and elbow range of motion impairment: call for a functional approach

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ABSTRACT

Background: To evaluate the effect of (new) treatments or analyze prevalence and risk factors of contractures, rating scales are used based on joint range of motion. However, cut-off points for levels of severity vary between scales, and it seems unclear how cut-off points relate to function. The purpose of this study was to compare severity ratings of different rating scales for the shoulder and elbow and relate these with functional range of motion.

Methods: Often used contracture severity rating scales in orthopedics, physiotherapy, and burns were included. Functional range of motion angles for the shoulder and elbow were derived from a recent synthesis published by our group. Shoulder flexion and elbow flexion range of motion data of patients three months after a burn injury were rated with each of the scales to illustrate the effects of differences in classifications. Secondly, the shoulder and elbow flexion range of motion angles were related to the required angles to perform over 50 different activities of daily living tasks.

Results: Eighteen rating scales were included (shoulder: 6, elbow: 12). Large differences in the number of severity levels and the cut-off points between scales were determined. Rating the measured range of motions with the different scales showed substantial inconsistency in the number of joints without impairment (shoulder: 14-36%, elbow: 26-100%) or with severe impairment (shoulder: <10%-29%, elbow 0%-17%). Cut-off points of most scales were not related to actual function in daily living.

Conclusion: There is an urgent need for rating scales that express the severity of contractures in terms of loss of functionality. This study proposes a direction for a solution.

INTRODUCTION

Many patients suffer from joint contractures as a secondary condition. These contractures include the shortening of muscle, tendon, ligament, or skin and can be a result of burn injury, adhesive capsulitis, bone fractures, plexus lesions, cerebral palsy, rheumatoid arthritis, spinal cord injury, stroke, multiple sclerosis,[1-11] and also aging.[12] Joint contractures are defined as a loss of range of motion (ROM) and may affect activities of daily living as well as participation and quality of life.[13-17] To evaluate the effect of (new) treatments or analyze prevalence and risk factors of contractures, many different rating scales are employed in orthopedics and physiotherapy. A rating scale can include only the ROM in a specific direction of movement of a specific joint or can be combined with other dimensions such as pain and muscle force to yield a summarized value for describing the impact of the impaired joint on the patient.[18]

Using scales to rate the severity of impaired ROM, however, is not without difficulties. First, the cut-off points for the levels of severity of different rating scales seem to vary which hampers comparing study results. Second, it seems to be ambiguous how the cut-off points of existing scales are related to function, a point that was also stressed in various earlier publications.[17,19-23] In the present study, therefore, different rating scales for the shoulder and elbow were compared, and their severity ratings contrasted to functional ROM. Actual patient data, in this case patients with burns, were used to clarify issues.

METHODS

The most often utilized rating scales for assessing loss of ROM were selected based on reviews on the evaluation of shoulder and elbow function and/or rating scales.[24-26] In addition, contracture severity scales used for burns were included.[17,19,27,28] The cut-off points for shoulder (forward) flexion and elbow flexion ROM were extracted. In the event that a rating scale combined ROM with other dimensions such as pain and muscle force, only information pertaining to ROM was included.

Functional range of motion angles for shoulder and elbow flexion were derived from a recent synthesis of available data performed by our group.[29,30] Briefly, data from 36 studies involving a total of 66 ADL tasks were included (see for search strategy and outcomes Oosterwijk et al.[29,30]). In these studies, shoulder (flexion, extension, abduction, and adduction) and/or elbow (flexion, extension) angles had been measured in healthy subjects naturally performing ADL tasks, and angles were provided per movement direction and task. Angles for shoulder and elbow flexion are available from 53 tasks.

To facilitate comparison between the severity levels of scales and functional angles, rating scales were arranged chronologically and translated to figures whereby normal ROM for shoulder flexion was established at 0-180° and elbow flexion at 0-150°.[11]

To illustrate the consequences of using different rating scales, range of motion data for shoulder (forward) flexion and elbow flexion of 39 patients three months after their burn injury were used. These data are part of a larger study in the Netherlands on contractures after burn injury. The study aim, design and procedures were discussed and approved by the research group of the Burn Center of the Martini Hospital Groningen. All procedures were in accordance with the ethical standards of the Helsinki declaration on ethical standards. The study protocol was reviewed by the Medical Ethical Committee (Martini Hospital Groningen no. 2011-19), which concluded no informed consent of patients was required, as the assessments concerned standard clinical practice. The patients included in the present study had been admitted to the burn center of Groningen in 2011-2012 with burns across or adjoining a total of 63 shoulder(s) and/or elbow(s) (see S1 Table for patient and burn characteristics). The patient's passive ROM was measured with a lateral goniometer (BaselineTM 12.5 inch, 3608 transparent plastic goniometer) according to the standardized protocols of Norkin and White.[31] Using these patient data, the severity of shoulder and elbow flexion impairment was determined by rating the measured ROM with each of the included rating scales. Secondly, to classify the functional consequences of impaired shoulder and elbow flexion, the ROM angle was related to functional angles per patient, i.e., to the angle required to perform ADL tasks.

RESULTS

Rating scales

In total, 18 scales that rate the severity of impaired ROM were included; six for the shoulder[17,19,27-28,32-34] and 12 for the elbow[17,19,27-28,35-42] (Tables 1 and 2). Nine scales[32-34,36-42] had additional items besides ROM to classify the severity of injury to the impaired joint (Tables 1 and 2).

Rating shoulder flexion

The six rating scales for shoulder flexion are shown in Figure 1. There were many differences in the numbers of levels and cut-off points between the levels. The Dobbs scale and the Schneider scale had fewest severity levels, i.e., three, while six levels were defined in the UCLA scale and the Constant score (Figure 1). The cut-off points of the Constant score, UCLA scale, and Schneider scale were rather similar; the only

Table 1 - Shoulder flexion rating scales.

Reference	Year	Scale name	Abbreviated scale name	Entirely ROM based
Dobbs and Curreri[27]	1972	Dobbs burn contracture scale	Dobbs scale	Yes
Huang et al.[28]	1977	Huang burn contracture scale	Huang scale	Yes
Ellman et al.[32]	1986	UCLA shoulder rating scale [a]	UCLA scale	No
Constant et al.[33,34]	1987/2008	Constant score	Constant score	No
Schneider et al.[19]	2006	Schneider burn contracture scale	Schneider scale	Yes
Niedzielski and Chapman[17]	2015	Burn Scar Contracture Severity Scale	BSC-SS	Yes

[a] UCLA: University of California at Los Angeles

Table 2 - Elbow flexion rating scales.

Reference	Year	Scale name	Abbreviated scale name	Entirely ROM based
Dobbs and Curreri[27]	1972	Dobbs burn contracture scale	Dobbs scale	Yes
Flynn et al.[35]	1974	Flynn Criteria	Flynn criteria	Yes
Ewald[36]	1975	Ewald scoring system	Ewald score	No
Huang et al.[28]	1977	Huang burn contracture scale	Huang scale	Yes
Inglis and Pellici[37]	1980	Hospital for Special Surgery scale	HSS	No
Morrey et al.[38]	1985	Mayo Elbow Performance Index	MEPI	No
Khalfayan et al.[39]	1992	Khalfayan scoring system	Khalfayan score	No
Morrey et al.[40]	1993	Mayo Elbow Performance Score	MEPS	No
Timmerman and Andrew[41]	1994	Timmerman-Andrew scoring system	T-A score	No
Sathyamoorthy et al.[42]	2004	Liverpool Elbow Score	LES	No
Schneider et al.[19]	2006	Schneider burn contracture scale	Schneider scale	Yes
Niedzielski and Chapman[17]	2015	Burn Scar Contracture Severity Scale	BSC-SS	Yes

difference is the number of levels. Concerning BSC-SS, a number of degrees were not allocated to a severity rating. The degrees falling in between the levels were classified to the nearest level.

Four of the scales have a level for 'no contracture'; in the Huang scale defined as 'none', in the BSC-SS defined as 'within functional limits (WFL)' and in the UCLA scale and Constant score receiving maximal points. The cut-off points of this 'no contracture' differed, i.e., 180° only, 151°-180°, ≥150°-180° and 165°-180° (Figure 1). The two other scales did not define a level for 'no contracture'. The largest obvious difference in cut-off points is found at the (very) severe level with a much higher ROM angle (<90° and ≤90°) in the Dobbs scale and BSC-SS compared to the others.

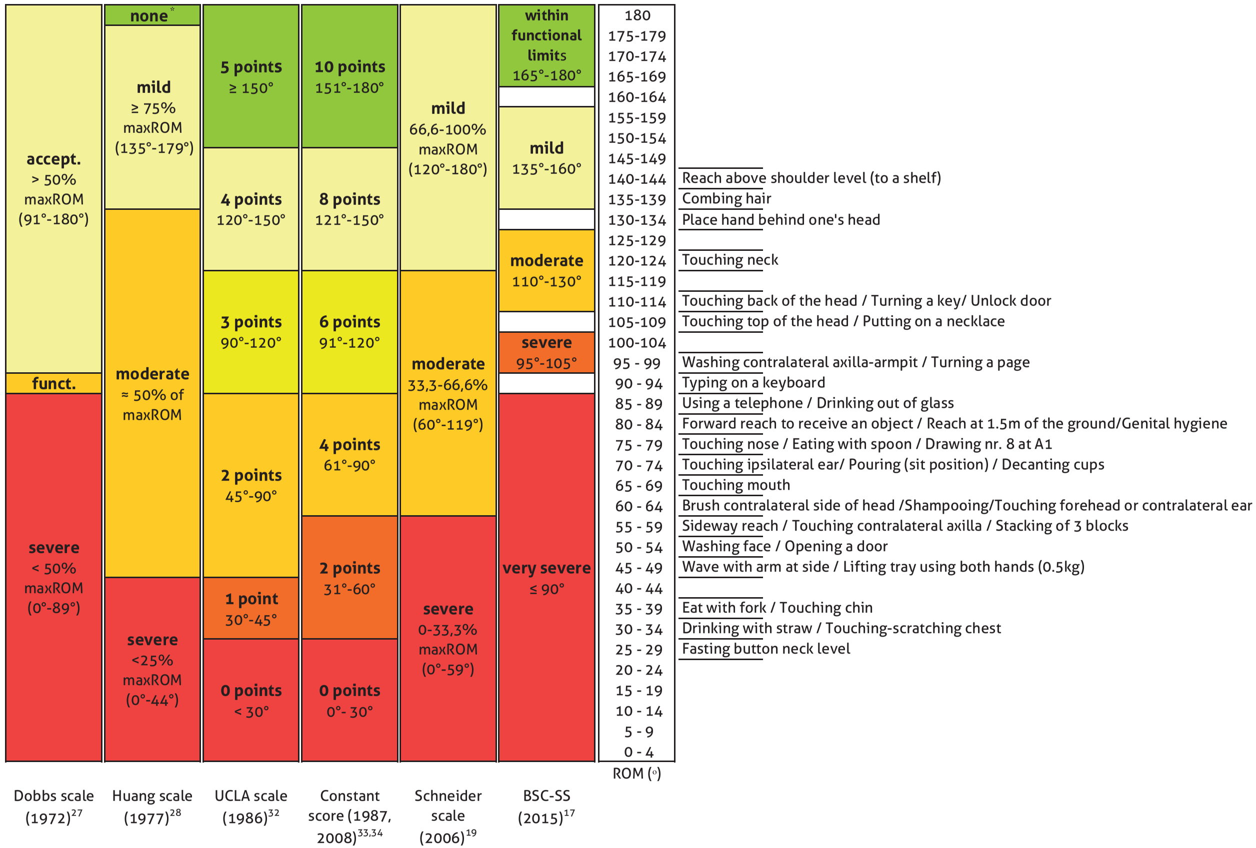

Figure 1 - Schematic illustration of shoulder flexion rating scales and their cut-off points per degrees of range of motion (ROM) as well as required shoulder flexion ROM for activities of daily life (ADL) as synthesized by Oosterwijk et al.[29,30] BSC-SS: Burn scar contracture severity scale; accept.: acceptable; funct.: functional = about 50% max ROM; *: none = no limitation of motion.

In terms of function, as ascertain from the literature,[29,30] shoulder flexion angles <25° were not required for any ADL task. Angles between 90° and 135° involved tasks for personal care whereby the hand needs to be placed on the upper body or head. Reaching above shoulder level (142°) was the task requiring the highest shoulder flexion angle. Comparing levels of severity to function (i.e., ROM angles required for ADL tasks), it was discovered that many tasks require angles in the middle range of the scales levels (Figure 1). If a contracture would prohibit performance of approximately 50% of these tasks, only the Dobbs scale and the BSC-SS would classify this as a severe contracture.

Rating elbow flexion

The twelve contracture severity scales for elbow flexion are shown in Figure 2. The range in number of severity levels was substantial, i.e., from two in the Ewald score to eight in the Khalfayan score. All others described three to five levels. Ten of the 12 scales had a level for 'no contracture' with the cut-off points for these ranging from ≥90° to ≥150°. Almost all of the scales included a (very) severe level. The cut-off points for the most severe level of impairment also differed considerably between the scales, ranging from <30° to <135°. The MEPS still allocates five points with zero degrees of ROM.

In terms of function, performance of many ADL tasks required a high degree of elbow flexion with 16 of the 45 tasks needing a flexion angle of ≥135°. These tasks mainly comprised tasks required for personal care and feeding, although the largest angle required was determined for 'using a telephone' (152°).[29,30] Comparing levels of severity to function (i.e., ROM angles required for ADL tasks), it was found that many tasks need angles located in the higher ranges of the scale's levels (Figure 2). If a contracture prohibited performance of these tasks, there was a large difference in how the severity of contracture would be rated from no impairment to a severe impairment.

ROM data applied to the contracture rating scales and expressed in terms of functionality

Shoulder flexion ROM data applied to contracture rating scales

To illustrate the implications of the different rating scales, actual patient data of 28 burned shoulders were used to rate shoulder flexion. The results of rating patient data in the contracture scales show that all levels of severity were found in all scales (Table 3). However, differences were discerned between scales. First, there was inconsistency in how many shoulders were rated as having 'no' shoulder flexion impairment (range 14-36%). Second, focusing on the other end of the scales, 29% of the shoulders were rated as being severely impaired based on the Dobbs scale and BSC-SS whereas all others scales classified less than 10% being severely impaired.

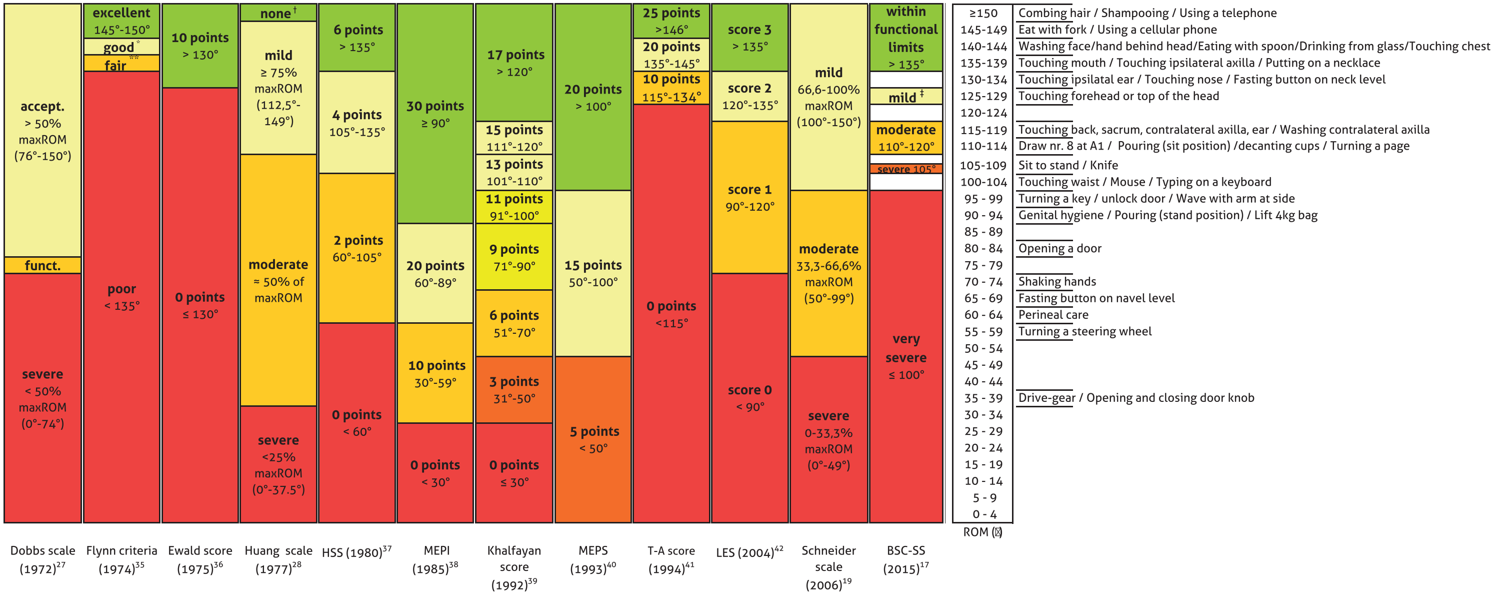

Figure 2 - Schematic illustration of elbow flexion rating scales and their cut-off points per degrees of range of motion (ROM) as well as required elbow flexion ROM for activities of daily life (ADL) as synthesized by Oosterwijk et al.[29,30] HSS: Hospital for special surgery scoring; MEPI: Mayo elbow performance index; MEPS: Mayo elbow performance score; T-A score: Timmerman-Andrew elbow score; LES: Liverpool elbow score; BSC-SS: Burn scar contracture severity scale; accept.: acceptable; funct.: functional = about 50% max ROM; *: good = 140°- 144°, ** fair = 135°- 139°, †: none = no limitation of motion, ‡: mild = 125°-130°.

Table 3 - Severity of shoulder flexion impairment according to six rating scales based on measured ROM of 28 shoulders three months post burn.

Dobbs scale		Huang scale		UCLA scale		Constant score		Schneider scale		BSC-SS	
Score	**%**	**Score**	**%**	**Pts**	**%**	**Pts**	**%**	**Score**	**%**	**Score (pts)**	**%**
Acceptable	71%	None	14%	5	36%	10	36%	Mild	64%	WFL (0)	18%
Functional	0%	Mild	43%	4	25%	8	25%	Moderate	29%	Mild (1)	43%
Severe	29%	Moderate	36%	3	11%	6	11%	Severe	7%	Moderate (2)	4%
		Severe	7%	2	21%	4	21%			Severe (3)	7%
				1	4%	2	4%			Very severe (4)	29%
				0	4%	0	4%				

4

Shoulder flexion ROM expressed in terms of functionality

Regarding the functional consequences, patients would be able to perform all ADL tasks with the ROM as measured in 57% (16/28) of the burned shoulders (Figure 3). The limitations in two shoulders (7%) would cause problems only in performing high reaching activities, combing hair, and touching the neck. The other ten (37%) burned shoulders would cause severe functional limitations with two shoulders causing very severe limitations (Figure 3).

The scales in which the cut-off value for severe contractures best compares to function are the Dobbs scale and the BCS-SS. The Dobbs scale classified 29% and the BSC-SS classified 36% of the shoulders as (very) severely limited. The upper two levels of the UCLA scale, Constant score, and BSC-SS would rate 61% of the shoulders as having no or little contracture which is nearest to the 57% having no functional problems, i.e., able to perform all ADL tasks.

Elbow flexion ROM data applied to contracture rating scales

Scoring elbow flexion data of 35 burned elbows with the twelve elbow rating scales showed that, in four scales (Dobbs scale, MEPI, MEPS, Schneider scale), all elbows scored on only one severity level (Table 4). In the HSS, Khalfayan score, and BSC-SS, all elbows scored in the upper levels but not in the lower levels of their scales.

Concerning 'no contracture', even larger differences were found for the elbow than for the shoulder, i.e., the percentage of elbows that scored maximally ranged from 100% (Dobbs scale, MEPI, MEPS, Schneider scale) to 26% (Huang scale). Elbow flexion angles corresponding to the most severe level were only determined by employing the Flynn criteria (17% scored poor), Ewald score (14% with 0 points), and T-A score (6% with 0 points).

Elbow flexion ROM data expressed in terms of functionality

Many of the ADL tasks required almost full elbow flexion so that even a small ROM deficit had considerable impact on ADL. Regarding functional consequences, with the ROM as measured in 26% (9/35) of the elbows, patients would be able to perform all ADL tasks. All other elbows (74%) would be more or less severely impaired (Figure 4). Comparing severity levels with the limitation in ADL functioning for elbow flexion, all rating scales underrate the impact of limitations in ROM of elbow flexion on daily functioning.

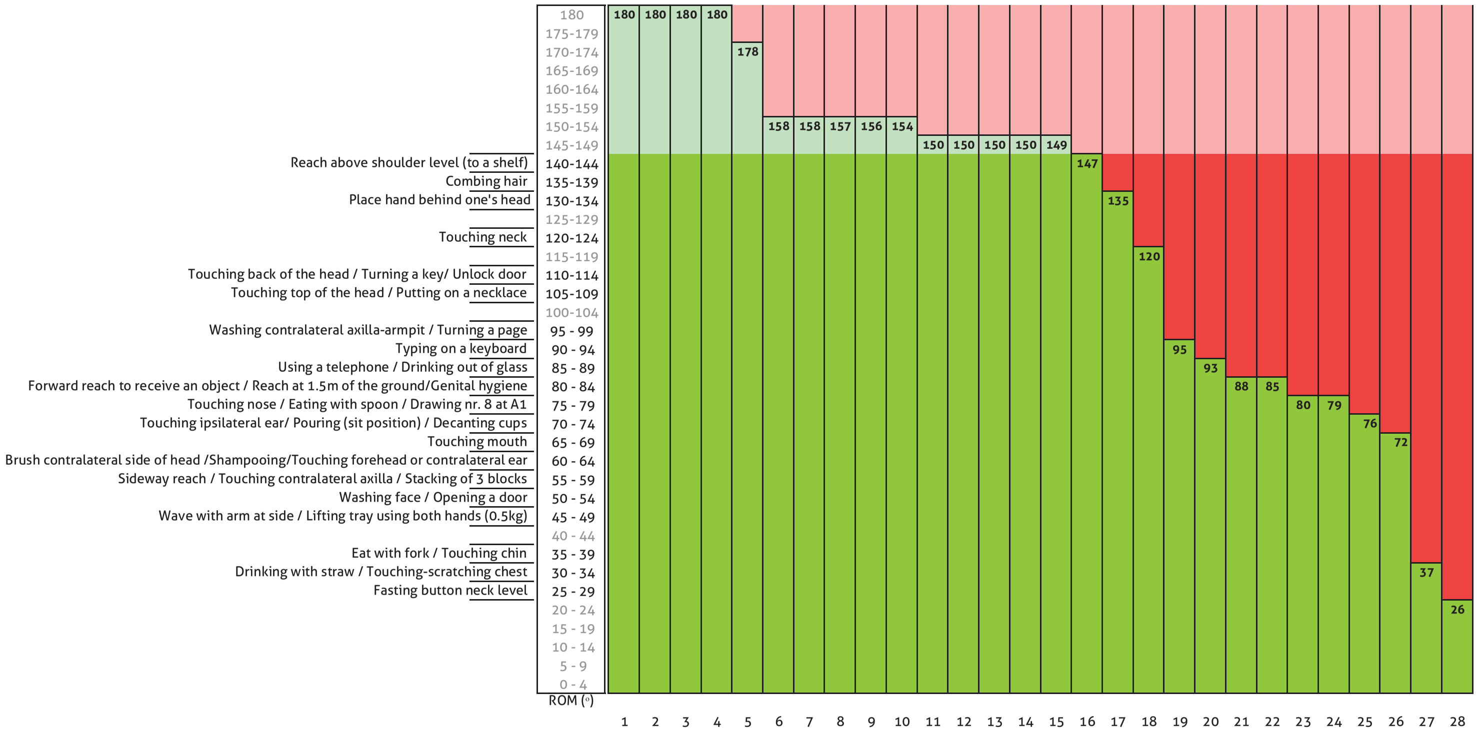

Figure 3 - Schematic illustration of activities of daily life (ADL) that can (dark green) or cannot (dark red) be performed after burn injury in the shoulder joint area, based on measured range of motion (ROM) of 28 shoulders 3 months post burn (ROM given in bold numbers) and the required shoulder flexion ROM for 36 different ADL tasks as synthesized by Oosterwijk et al.[29,30] Light green and light red represent joint angles that can or cannot be performed, respectively, but do not affect functionality based on the included tasks. Note that not many of the tasks need near full (145°-180°) shoulder flexion ROM meaning that up to 35° ROM deficit might have rather limited impact on daily functioning.

Table 4 - Severity of elbow flexion impairment according to 12 rating scales based on measured ROM of 35 elbows three months post burn.

Dobbs scale		Flynn Criteria		Ewald Score		Huang scale		HSS		MEPI	
Score	%	Score	%	Pts	%	Score	%	Pts	%	Pts	%
Acceptable	100%	Excellent	49%	10	86%	None	26%	6	80%	30	100%
Functional	0%	Good	23%	0	14%	Mild	54%	4	20%	20	0%
Severe	0%	Fair	11%			Moderate	20%	2	0%	10	0%
		Poor	17%			Severe	0%	0	0%	0	0%

Table 4 - *Continued.*

Khalfayan score		MEPS		T-A score		LES		Schneider scale		BSC-SS	
Pts	%	Pts	%	Pts	%	Pts	%	Score	%	Score (pts)	%
17	91%	20	100%	25	31%	3	80%	Mild	100%	WFL (0)	83%
15	6%	15	0%	20	51%	2	11%	Moderate	0%	Mild (1)	9%
13	3%	5	0%	10	11%	1	9%	Severe	0%	Moderate (2)	9%
11	0%			0	6%	0	0%			Severe (3)	0%
9	0%									Very severe (4)	0%
7	0%										
5	0%										
3	0%										
0	0%										

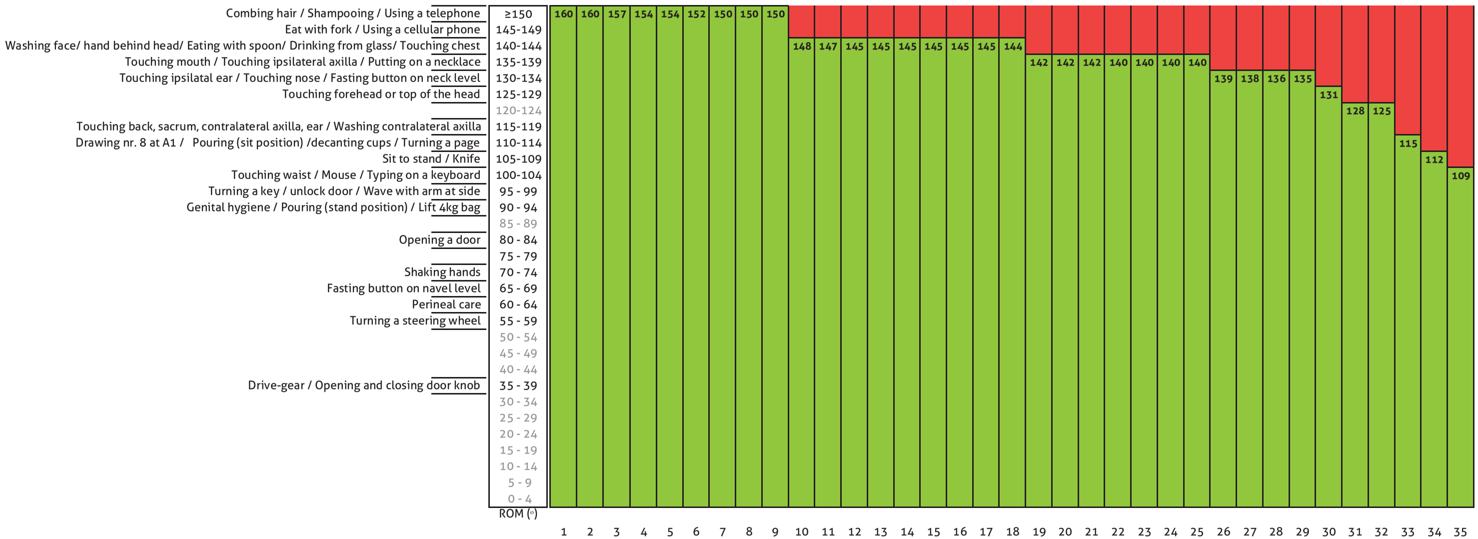

Figure 4 - Schematic illustration of activities of daily life (ADL) that can (green) or cannot (red) be performed after burn injury in the elbow joint area, based on measured range of motion (ROM) of 35 elbows 3 months post burn (ROM given in bold numbers) and the required elbow flexion ROM for 44 different ADL tasks as synthesized by Oosterwijk et al.[29,30] Note that many of these ADL tasks need almost full elbow flexion so that even a small ROM deficit can have considerable impact on daily functioning.

DISCUSSION

In the present study, different rating scales for the shoulder and the elbow were compared, and their severity ratings contrasted with functional ROM. Large differences in the number of severity levels and angles corresponding to cut-off points between scales were determined. Rating the measured ROMs with the different scales demonstrated substantial inconsistency in how many joints were classified as having no contracture (shoulder: 14%-36%, elbow: 0%-100%) and, at the other end of the spectrum, a severe contracture (shoulder: 4%-29%, elbow 26%-100%). As indicated before, there is an urgent need for scales that express the severity of contractures in terms of function. The present review emphasizes this by showing that cut-off points of most included scales were not related to function. When comparing severity levels with the limitation in ADL functioning for elbow flexion, all rating scales underrated the impact on daily functioning.

Concerning the used scales, the lower part of the Dobbs scale and BSC-SS and the upper part of the Constant score, UCLA scale, and BSC-SS seem most in accordance with shoulder flexion function. For elbow flexion, the Flynn criteria is most in line with function because of the extensive level of 'severe' that is included in this scale. Considering the available data, we suggest an upper cut-off point of 145° and lower cut-off point of approximately 95° for the shoulder flexion whereby an active shoulder flexion of more than 145° corresponds to no functional contracture and less than 95° of active shoulder flexion corresponds to a (very) severe functional contracture. For elbow flexion, we suggest an upper cut-off point of 150° with >150° meaning 'no contracture' or 'no functional limitations' and a lower cut-off point of 140° with <140° meaning a contracture with (very) severe functional consequences. Discussion is open for the ROM in between and the number of levels whereby levels are based preferably on clinically minimally important differences and taking into account imprecision of assessment especially when goniometry is used.[43]

Concerning the distribution of tasks over the total range of motion per joint,[29,30] it is clear that a rating scale with the same cut-off points for all joints cannot be viable. Even the various movement directions of the same joint have different distributions of tasks over the total range of motion. Therefore, for each joint and movement direction, a specific functional scale should be developed.

Limitations

First, we did not perform a systematic literature review to unearth all of the rating scales but used the scales that are commonly utilized as evidenced from review articles. In this aspect, we think we have included the most obvious and relevant rating scales. Second, angles required for functional range of motion were based on the information of all tasks that were available from the literature, i.e., from a total of 53 ADL tasks for shoulder flexion and elbow flexion. This information on available tasks, however, does not cover all daily activities, for example, dressing tasks could not be included as they have not yet been assessed. This may be explained by the fact that putting on clothes would cover markers necessary for assessment. When such data becomes available, interpretation including the differentiation of cut-off points may change. Furthermore, the required ROM per ADL task ascertain in the review[29,30] were based on active ROM whereas the data from patients with burns were passive ROM; though, in our opinion, this does not change the conclusions of this study. Finally, task execution can be influenced by age, gender, hand dominance, and/or a postural or upper limb length variability[44-48] and, therefore, the functional angles will not be representative for each individual.

The relevance of the range of motion of shoulder and elbow joints for an individual is more than can be covered by ADL tasks. Depending on individual wishes and demands on the mobility of these joints concerning, for example, work and leisure time activities, the ROM angles that are needed may vary. Furthermore, during task execution, multiple joints move together in a chain. Therapists will have to keep this in mind in their treatment of individual patients. When comparing the effectiveness of different treatment strategies or evaluating prevalence and risks factors, the functional relevance of ROM angles in terms of ADL as a universal demand on ROM is a good starting point.

Further research

To derive a more functional scale to rate the severity of contractures, further research should focus on expanding the amount and diversity of tasks (including, for example, dressing tasks) and being aware of the differences of participant's characteristics. Furthermore, to optimize and tailor interventions to maintain or improve mobility, additional research is required on the correlation between objective ROM impairment and problems in ADL as well as participation and quality of life as experienced by patients. In reality, it is possible that a ROM impairment is not considered a problem as the patient is able to perform all activities with compensatory movements (i.e., using surrounding joints or the other arm). However, compensatory movements can lead to serious secondary conditions such as overuse of muscles around the affected joint, an increased risk of soft tissue problems and degenerative joint diseases.[49-51] In this regard, it would not only be relevant to know which ROM angles are required but also how often extreme ROMs are used during the course of a day. Maintaining or restoring ROM to be able to naturally perform ADL tasks is crucial whereas evaluation of compensatory movements should be a focus for further research. Finally, we have made a start in the functional approach for shoulder and elbow flexion, but more research is necessary for other joints and movement directions in healthy and impaired participants.

CONCLUSION

The use of various different classifications for the shoulder and elbow obscures the true impact of contractures and, therefore, hampers clinical practice as well as research. There is an urgent need for rating scales expressing the severity of contractures in terms of loss of function. This study provides some solution indications, but much work is still needed. We hope to have encouraged discussion and further research.

Author Contributions

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REFERENCES

1. Oosterwijk AM, Mouton LJ, Schouten H, Disseldorp LM, van der Schans CP, Nieuwenhuis MK. Prevalence of scar contractures after burn: A systematic review. Burns. 2017;43:41-9.
2. Willig TN, Bach JR, Rouffet MJ, Krivickas LS, Maquet C. Correlation of flexion contractures with upper extremity function and pain for spinal muscular atrophy and congenital myopathy patients. Am J Phys Med Rehabil. 1995;74:33-8.
3. Magermans DJ, Chadwick EK, Veeger HE, van der Helm FC. Requirements for upper extremity motions during activities of daily living. Clin Biomech. 2005;20:591-9.
4. Fergusson D, Hutton B, Drodge A. The epidemiology of major joint contractures: A systematic review of the literature. Clin Orthop Relat Res. 2007;456:22-9.
5. Petuskey K, Bagley A, Abdala E, James MA, Rab G. Upper extremity kinematics during functional activities: Three-dimensional studies in a normal pediatric population. Gait Posture. 2007;25:573-9.
6. van Andel CJ, Wolterbeek N, Doorenbosch CA, Veeger DH, Harlaar J. Complete 3D kinematics of upper extremity functional tasks. Gait Posture. 2008;27:120-7.
7. Kim K, Park DS, Ko BW, Lee J, Yang SN, Kim J, et al. Arm motion analysis of stroke patients in activities of daily living tasks: a preliminary study. Conf Proc IEEE Eng Med Biol Soc. 2011; 1287-91.
8. Skalsky AJ, McDonald CM. Prevention and management of limb contractures in neuromuscular diseases. Phys Med Rehabil Clin N Am. 2012;23:675-87.
9. Klotz MC, Kost L, Braatz F, Ewerbeck V, Heitzmann D, Gantz S, et al. Motion capture of the upper extremity during activities of daily living in patients with spastic hemiplegic cerebral palsy. Gait Posture. 2013;38:148-52.
10. Hoang PD, Gandevia SC, Herbert RD. Prevalence of joint contractures and muscle weakness in people with multiple sclerosis. Disabil Rehabil. 2014;36:1588-93.
11. Magee DJ. Orthopedic physical assessment, 5th ed. St. Louis, Saunders Elsevier; 2008.
12. Offenbächer M, Sauer S, Riess J, Müller M, Grill E, Daubner A, et al. Contractures with special reference in elderly: definition and risk factors - a systematic review with practical implications. Disabil Rehabil. 2014;36:529-38.
13. Leblebici B, Adam M, Bagis S, Tarim AM, Noyan T, Akman MN, et al. Quality of life after burn injury: the impact of joint contracture. J Burn Care Res 2006;27:864-8.
14. Heise M, Müller M, Fischer U, Grill E. Quality of life in older individuals with joint contractures in geriatric care settings. Qual Life Res. 2016;25:2269-81.
15. Bartoszek G, Fischer U, Grill E, Muller M, Nadolny S, Meyer G. Impact of joint contracture on older persons in a geriatric setting: A cross-sectional study. Z Gerontol Geriatr. 2015;48:625-32.
16. Engstrand C, Krevers B, Nylander G, Kvist J. Hand function and quality of life before and after fasciectomy for Dupuytren contracture. J Hand Surg Am. 2014;39:1333-43.
17. Niedzielski LS, Chapman MT. Changes in burn scar contracture: utilization of a severity scale and predictor of return to duty for service members. J Burn Care Res. 2015;36:e212-9.
18. The B, Reininga IH, El Moumni M, Eygendaal D. Elbow-specific clinical rating systems: extent of established validity, reliability, and responsiveness. J Shoulder Elbow Surg. 2013;22:1380-94.
19. Schneider JC, Holavanahalli R, Helm P, Goldstein R, Kowalske K. Contractures in

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burn injury: defining the problem. J Burn Care Res. 2006;27:508-14.
20. Korp K, Richard R, Hawkins D. Refining the idiom "functional range of motion" related to burn recovery. J Burn Care Res. 2015;36:e136-45.
21. Fradet L, Liefhold B, Rettig O, Bruckner T, Akbar M, Wolf SI. Proposition of a protocol to evaluate upper-extremity functional deficits and compensation mechanisms: application to elbow contracture. J Orthop Sci. 2015;20:321-30.
22. Clavet H, Hébert PC, Fergusson D, Doucette S, Trudel G. Joint contracture following prolonged stay in the intensive care unit. CMAJ. 2008;178:691-7.
23. Parry I, Walker K, Niszczak J, Palmieri T, Greenhalgh D. Methods and tools used for the measurement of burn scar contracture. J Burn Care Res. 2010;31:888-903.
24. Kirkley A, Griffin S, Dainty K. Scoring systems for the functional assessment of the shoulder. Arthroscopy. 2003;19:1109-20.
25. Smith MV, Calfee RP, Baumgarten KM, Brophy RH, Wright RW. Upper extremity-specific measures of disability and outcomes in orthopaedic surgery. J Bone Joint Surg Am. 2012;94:277-85.
26. Longo UG, Franceschi F, Loppini M, Maffulli N, Denaro V. Rating systems for evaluation of the elbow. Br Med Bull. 2008;87:131-61.
27. Dobbs ER, Curreri PW. Burns: analysis of results of physical therapy in 681 patients. J Trauma. 1972;12:242-8.
28. Huang TT, Blackwell SJ, Lewis SR. Ten years of experience in managing patients with burn contractures of axilla, elbow, wrist, and knee joints. Plast Reconstr Surg. 1978;61:70-6.
29. Oosterwijk AM, Nieuwenhuis MK, van der Schans CP, Mouton LJ. Required shoulder and elbow: joint angles in daily living tasks: an overview. Ann Burns Fire Disasters. 2015;28: S160.
30. Oosterwijk AM, Nieuwenhuis MK, van der Schans CP, Mouton LJ. Shoulder and elbow range of motion for the performance of activities of daily living: a Systematic Review. Physiother Theory Pract. 2018;34:505-28.
31. Norkin CC, White DJ. Measurement of joint motion: a guide to goniometry. 4th ed. Portland: FA Davis Company; 2009.
32. Ellman H, Hanker G, Bayer M. Repair of the rotator cuff. End-result study of factors influencing reconstruction. J Bone Joint Surg Am. 1986;68:1136-44.
33. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res.1987;214:160-4.
34. Constant CR, Gerber C, Emery RJ, Søjbjerg JO, Gohlke F, Boileau P. A review of the Constant score: modifications and guidelines for its use. J Shoulder Elbow Surg. 2008;17:355-61.
35. Flynn JC, Matthews JG, Benoit RL. Blind pinning of displaced supracondylar fractures of the humerus in children. Sixteen years' experience with long-term follow-up. J Bone Joint Surg Am. 1974;56:263-72.
36. Ewald FC. Total elbow replacement. Orthop Clin North Am. 1975;6:685-96.
37. Inglis AE, Pellicci PM. Total elbow replacement. J Bone Joint Surg Am. 1980;62:1252-8.
38. Morrey BF. Revision total elbow arthroplasty. In: Kashiwagi D, ed. Elbow Joint, International Congress Series 678. New York: Excerpta Medica. 1985:327-35.
39. Khalfayan EE, Culp RW, Alexander AH. Mason type II radial head fractures: operative versus nonoperative treatment. J Orthop Trauma. 1992;6:283-9.
40. Morrey BF, An KN, Chao EYS. Functional evaluation of the elbow. In: Morrey BF, ed. The Elbow and Its Disorders, 2nd ed. Philadelphia: WB Saunders. 1993:86-97.

41. Timmerman LA, Andrews JR. Arthroscopic treatment of posttraumatic elbow pain and stiffness. Am J Sports Med. 1994;22:230-5.
42. Sathyamoorthy P, Kemp GJ, Rawal A, Rayner V, Frostick SP. Development and validation of an elbow score. Rheumatology (Oxford). 2004;43:1434-40.
43. Edgar D, Finlay V, Wu A, Wood F. Goniometry and linear assessments to monitor movement outcomes: are they reliable tools in burn survivors? Burns. 2009;35:58-62.
44. Barnes CJ, Van Steyn SJ, Fischer RA. The effects of age, sex, and shoulder dominance on range of motion of the shoulder. J Shoulder Elbow Surg. 2001;10:242-6.
45. Doriot N, Wang X. Effects of age and gender on maximum voluntary range of motion of the upper body joints. Ergonomics. 2006; 49:269-81.
46. Medeiros HB, de Araujo DS, de Araujo CG. Age-related mobility loss is joint-specific: An analysis from 6,000 flexitest results. Age (Dordr). 2013;35:2399-2407.
47. Stathokostas L, McDonald MW, Little RM, Paterson DH. Flexibility of older adults aged 55±86 years and the influence of physical activity. J Aging Res. 2013;743843:1-8.
48. Chapleau J, Canet F, Petit Y, Sandman E, Laflamme GY, Rouleau DM. Demographic and anthropometric factors affecting elbow range of motion in healthy adults. J Shoulder Elbow Surg. 2013;22:88-93.
49. de Groot JH, Angulo SM, Meskers CG, van der Heijden-Maessen HC, Arendzen JH. Reduced elbow mobility affects the flexion or extension domain in activities of daily living. Clin Biomech. 2011;26:713-7.
50. Mell AG, Childress BL, Hughes RE. The effect of wearing a wrist splint on shoulder kinematics during object manipulation. Arch Phys Med Rehabil. 2005;86:1661-4.
51. Veeger HE, Magermans DJ, Nagels J, Chadwick EK, van der Helm FC. A kinematical analysis of the shoulder after arthroplasty during a hair combing task. Clin Biomech. 2006;21 Suppl 1:S39-44.

SUPPORTING INFORMATION

S1 Table - Demographic and medical characteristics of the study population.

		Total#	Shoulder	Elbow
N subjects		39	20	26
N burned shoulder/ elbow		63	28	35
Location burn injury	Left side	-	4	4
	Right side	-	8	13
	Bilateral	-	8	9
Sex (% male)		62	55	69
Age (mean (sd) in years)		37.8 (23.0)	43.0 (24.3)	34.3 (22.1)
Age (range in years)		0 - 79	0 - 79	0 - 65
TBSA (mean (sd) in %)		14.8 (16.2)	17.2 (14.4)	15.8 (17.2)
TBSA (range in %)		-	1 - 48%	1 - 66%
Full thickness TBSA (mean (sd) %)		3.5 (8.9)	4.5 (8.5)	4.7 (10.5)
LOS (mean (sd) days)		29.8 (22.4)	34.4 (18.2)	30.3 (25.6)

In some patients more than one joint is burned; TBSA: Total Body Surface Area; LOS: Length of stay at the hospital.

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Joint flexibility problems and the impact of its operationalization

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ABSTRACT

Background: Dissatisfaction is being voiced with the generally used way joint flexibility problems are defined (operationalized), i.e., as a range of motion (ROM) one or more degrees lower than normative ROM of healthy subjects. Other, specifically more function-related operationalizations have been proposed. The current study evaluated the effect of applying different operationalizations of joint flexibility problems on its prevalence.

Method: ROM data of 95 joints affected by burns of 23 children were used, and data on 18 functional activities (Burn Outcome Questionnaire (BOQ)). Five methods were used to operationalize joint flexibility problems: (1) ROM below normative ROM, (2) ROM below normative ROM minus 1SD, (3) ROM below normative ROM minus 2SD, (4) ROM below functional ROM, and (5) a score of 2 or more on the Likert Scale (BOQ).

Results: Prevalence of joint flexibility problems on a group level ranged from 13% to 100% depending on the operationalization used. Per joint and movement direction, prevalence ranged from 40% to 100% (Method 1) and 0% to 80% (Methods 2 - 4). 18% of the children received '2' on the Likert Scale (Method 5).

Conclusion: The operationalization of joint flexibility problems substantially influences prevalence, both on group and joint level. Changing to a function-related operationalization seems valuable; however, international consensus is required regarding its adoption.

Trial registration: The study is registered in the National Academic Research and Collaborations Information System of the Netherlands (OND1348800).

INTRODUCTION

Joint flexibility is immensely important for the performance of activities of daily living (ADL).[1-3] Burn injuries as well as many neurological and orthopedic conditions, however, can affect joint flexibility.[4] The usual way to translate a joint flexibility problem into a measurable variable is to compare the measured range of motion (ROM) of a specific joint and movement direction with the normative ROM value, i.e., the mean maximal ROM of healthy subjects.[5-8] According to this operationalization, a measured ROM of one or more degrees lower than the normative ROM is defined as a joint flexibility problem.[9-15] This normative ROM operationalization of joint flexibility problems is leading in registration and research. It is used to determine the prevalence of joint flexibility problems and to compare and evaluate the outcome of treatment and care over time and between different health care centers.[16] In clinical practice however, the patient, common sense, and experience determines when a limited joint flexibility is a risk or a problem, specifically in terms of function. It can be strongly doubted therefore, whether the most often used normative ROM operationalization of joint flexibility problems is the most suitable, especially as it obviously does not reflect clinical practice.

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What are the alternatives? One is following the reasoning of the World Health Organization (WHO) on their operationalization of the problem of obesity in children. In that case, a distinction is made between 'no weight problem', 'at risk for obesity', and 'obese' whereby between one and two standard deviations (SD) above the median body mass index is defined as 'at risk' and more than 2SD above the median is 'obese'.[17] Using this reasoning for the operationalization of joint flexibility problems would mean that a measured ROM between one SD and two SD below the normative value means 'at risk' for joint flexibility problems and more than 2SD below the normative value indicates a 'joint flexibility problem'.

Another alternative for the operationalization of joint flexibility problems is in terms of function, i.e., defining a joint flexibility problem by comparing a measured ROM to the ROM necessary for functioning. Functional ROM is the ROM that healthy subjects actually use for performing activities of daily living. Throughout the years, this alternative has been advocated in the literature on burn contractures.[9,15,16,18-21] A prerequisite for applying this operationalization is knowing the functional ROM of all joints and movement directions. Recently, Korp et al.[20] made a start in making such data accessible through a review of the literature, and our detailed systematic review of the literature extends the information, specifically concerning the shoulder and elbow.[22]

Finally, besides the ROM-based operationalizations, an alternative is to evaluate joint flexibility problems in terms of whether a person experiences difficulties in daily living, assessed by patient-report outcome measures.

Clearly, different operationalizations of joint flexibility problems are possible. The aim of the present study was to demonstrate the effect of using different operationalizations of joint flexibility problems on its prevalence.

METHOD

In the present study, the STROBE guidelines for reporting were used.[23]

Study and subject characteristics

Data were collected between October and November 2012 as part of the cross-sectional study of Disseldorp et al.[24] (National Academic Research and Collaborations Information System of the Netherlands number: OND1348800; The Medical Ethical Committee of University Medical Center Groningen approved this study: NL40183.042.12). The total cohort study comprised the assessment of exercise capacity (incremental maximal exercise test on an electronically braked cycle ergometer), body composition (body mass index, waist circumference and skinfold thickness), muscular strength (hand-held dynamometer), and joint range of motion (goniometer). Assessments were done in a mobile exercise lab near to the subjects home by two researchers (LMD, AMO). Physical activity and sedentary behavior were assessed by accelerometry during one week and questionnaires (Subscale Dutch Standard Questionnaire for Activity, Subscale FIT Norm, Subscale Dutch Activity Norm). Furthermore, questionnaires were used to assess perceived fatigue (PedsQL Multidimensional Fatigue Scale) and health-related quality of life (Burn Outcome Questionnaire (BOQ)). Included were 24 children (6-18 years old) that had been admitted to a Dutch burn center with >10% Total Body Surface Area (TBSA) burned, a length of stay of more than six weeks, or both, and the burn injury having occurred between six months and five years before measurement. Excluded were subjects with (pre-existing) comorbidity, (mental) disabilities or insufficient Dutch language proficiency. Written informed consent was provided by all parents (or legal representatives) as well as by subjects aged ≥12 years before enrolment; for subjects aged 18 parental informed consent was not required. The subject enrolment is described in Figure 1. The subject and burn characteristics are described including the extent and depth of the burn, location of burn, length of stay at the hospital, and surgery (Table 1).

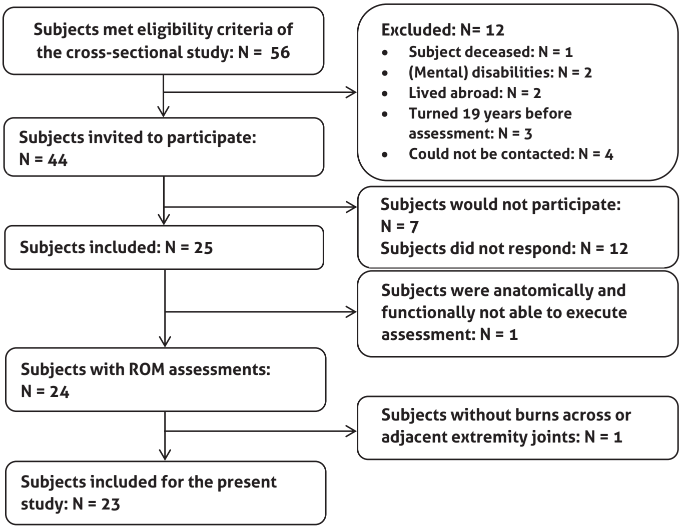

Figure 1 - Flow chart of subject enrolment.

Table 1 - Subject and burn characteristics.

Characteristics	N	%	Mean ± SD	Median	IQR	Mode	Range
Number of children included	23						
Age at injury (years)			7.5 ± 4.3	8	6	8	1-16
Age at assessment (years)			10.6 ± 3.8	9	5.5	7	6-18
Time between injury and assessment (years)			3.0 ± 1.1	3	1.4	2.8	1-5
Male subjects	14	61%					
% TBSA burned			18.2 ± 8.4	16	9.8	10	10-41
<20%	16	70%					
≥20%, <30%	4	17%					
≥30%	3	13%					
Full thickness burns (%TBSA)			6.1 ± 9.0	2	8	0	0-41
Subjects with arm burns	18	78%					
Subjects with leg burns	14	61%					
Length of hospital stay (days)			29.2 ± 13.6	24	9.5	24	16-78
≤3 weeks	5	22%					
>3 weeks, ≤4 weeks	12	52%					
>4 weeks, ≤5 weeks	1	4%					
>5 weeks	5	22%					
Number of children with surgery	21	91%					
Number of surgeries			1.7 ± 1.5	1	1	1	0-7
Number of children with reconstructive surgery[a]	5	22%					
Number of reconstructive surgeries[a]			0.4 ± 0.8	0	0	0	0-3

IQR: Interquartile range between Q1 and Q3. [a] Reconstructive surgeries before time of assessment.

Collection of ROM and functional outcome data

In the present study, ROM data and scores on 18 items of the BOQ were used. Passive ROM was measured in degrees according to the standardized protocol described by Klerks et al.[7] using a goniometer (Gollehon extendable goniometer 01135, Lafayette Instrument, Lafayette, U.S.A.). Goniometry has shown to be reliable for the assessment of joint ROM in patients with burns.[25] ROM was measured in the shoulder (flexion), elbow (flexion and extension), wrist (dorsal and palmar flexion), knee (flexion and extension), and ankle (plantar and dorsal flexion) on the dominant side of the body. In the event that there were burn scars across or adjacent to a specific joint, this joint was measured on both sides of the body,[24] except if no evident burn scar was seen at time of measurement. Being adjacent to a joint was defined as a burn at a maximum distance of 1/3 of the length of the adjoining body part/limb.

The presence and severity of functional problems were subjectively scored on the 18 functional items of the validated Dutch version of the American Burn Association/ Shriners' Hospital Children Burn Outcome Questionnaire. These 18 items comprise questions on upper extremity function (seven items), physical function/sports (six items), and transfers/mobility (five items) during activities of daily living.[24,26,27] The presence and severity of a functional problem was scored per activity on a 4-point Likert Scale except for 'How often does this child/do you need help from another person for walking and climbing', which was scored on a 5-point Likert Scale. A higher score on the Likert Scale reflects a child having more difficulties in performing an activity, i.e., on the 4-point Likert Scale a score of '1' means 'easy', '2' means 'a little hard', '3' means 'very hard', '4' means 'can't do'; on the 5-point Likert Scale a score of '1' means 'never', '2' means 'sometimes', '3' means 'about half of the time', '4' means 'often', '5' means 'all of the time'. The BOQ has a parental proxy and adolescent version. The parental proxy version was used for the children of 6-11 years of age and the adolescent version for those aged 12-18 years old.

Different operationalizations of joint flexibility problems

Joint flexibility problems were determined based on five different operationalizations. A joint flexibility problem was operationalized as being present when the measured ROM was (1) one degree or more below the age matched Dutch normative value;[14] (2) one SD below these normative values; (3) two SD below these normative values; or (4) below the functional ROM. For functional ROM, data from Korp et al.[20] were used regarding the wrist, knee, and ankle joints and from Oosterwijk et al.[22] regarding the shoulder and elbow joints. These cut-off points are reflecting the ROM that is used by healthy subjects to complete ADL tasks without compensatory movements (Table 2). Finally, joint flexibility problems were operationalized as being present if: (5) a score of 2 or more on the Likert Scale on any of the 18 functional items of de BOQ was given.

Table 2 - Cut-off values for ROM per joint and movement direction used for the operationalization of joint flexibility problems.

Method	Shoulder Flexion	Elbow Flexion	Elbow Extension[c]	Wrist Palmar Flexion	Wrist Dorsal Flexion	Knee Flexion	Knee Extension[c]	Ankle Plantar Flexion	Ankle Dorsal Flexion
1) Normative values[a]	180°	154°	10°	108°	97°	155°	7°	62°	24°
2) Normative values[a] minus 1SD	166°	148°	4°	94°	87°	149°	3°	51°	16°
3) Normative values[a] minus 2SD	152°	142°	-2°	80°	77°	143°	-1°	42°	8°
4) Functional ROM[b]	142°	152°	-1°	54°	63°	138°	0°	32°	36°

[a] Age matched Dutch normative values of Klerks et al.[7] [b] Functional ROMs of Oosterwijk et al.[22] for shoulder and elbow; functional ROMs of Korp et al.[20] for wrist, knee, ankle. [c] A positive number for extension means hyperextension; when the zero-position cannot be performed (elbow or knee completely straight), the limitation is described with a minus sign.

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Calculations of prevalences

Per operationalization method, the prevalence of joint flexibility problems was calculated for the entire group of children, i.e., what percentage of them had a joint flexibility problem in any of the measured movement directions of a joint with a burn across or adjacent to it (Method 1-4). For experienced functional problems (Method 5), the prevalence was determined as the percentage of subjects that scored 2 or more on one or more of the 18 BOQ items. Furthermore, the prevalence of joint flexibility problems was calculated per measured movement direction for Method 1-4, i.e., what percentage of this population had a joint flexibility problem in a specific movement direction per joint with a burn across or adjacent to it. This was not possible for Method 5 as problems are scored per functional activity on a Likert Scale and are therefore not joint-specific. Calculated prevalences were compared with each other in a descriptive analysis.

RESULTS

In the 23 subjects included for the present study, there were 112 joints with a burn across or adjacent. For the present study, ROM data of 95 of these joints (85%) were included for calculating the prevalence of joint flexibility problems as the other joints had not been assessed as no burn scars were evident at the time of measurement. The BOQ data were available for 22 subjects: 14 for subjects 6-11 years old and eight for subjects 12-18 years old. For one subject (≥12 years old), the questionnaire was lost in the post and therefore not available for data-analysis.

Group level

Prevalence of joint flexibility per operationalization method

The prevalence of joint flexibility problems on group level according to Method 1 was 100%, meaning that all of the 23 children were classified as having a problem in at least one movement direction of the upper or lower extremity. According to Methods 2 and 3, both based on the normative ROM but taking 1SD or 2SD into account, resulted in a prevalence of joint flexibility problems of 43% and 13%, respectively. Prevalences calculated according to Methods 4 and 5, each taking function into account, were 61% and 18% respectively (Table 3).

Comparison of prevalences

Comparing the prevalences on group level exposed substantial differences. Prevalence was highest, by far, based on normative ROM without taking SD into account.

None of the methods gave identical results to others, though the prevalences of the operationalizations ROM minus 2SD (Method 3) and the experienced functional outcome (Method 5) were rather similar (<20%).

Table 3 - Prevalence (%) of joint flexibility problems in children 1-5 years post burn as calculated with 5 different methods.

Method		N assessed	N with joint flexibility problem(s)	Prevalence (%) of joint flexibility problems
1	ROM < Normative value [a]	23	23	100%
2	ROM < Normative value [a] minus 1SD	23	10	43%
3	ROM < Normative value [a] minus 2SD	23	3	13%
4	ROM < Functional ROM [b]	23	14	61%
5	BOQ	22	4	18%

[a] Age matched Dutch normative values of Klerks et al.[7] [b] Functional ROMs of Oosterwijk et al.[22] for shoulder and elbow; functional ROMs of Korp et al.[20] for wrist, knee, ankle.

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Per movement direction per joint

Prevalence of joint flexibility per operationalization method

Using Method 1, the prevalence of joint flexibility problems per movement direction per joint ranged from 40% for ankle plantar and dorsal flexion up to 100% for shoulder flexion (Table 4). For Methods 2 and 3, the prevalence per movement direction ranged from 0% to 20% and from 0% to 10%, respectively (Table 4). Regarding functional limitations (Method 4), the prevalence per joint ranged from 0% for the most movement directions to 80% for ankle dorsal flexion (Table 4).

Of four subjects (all ≤11 years), the parents scored that the performance of one or two functional tasks were ‘a little hard’ for their child (2 on the 4-point Likert Scale) (Table 5). Performance of these tasks seemed to correspond with the location of the burns except in one subject whereby fastening buttons was ‘a little hard‘ whereas the burns were located on the individual’s legs (Table 5). However, clear relations between specific BOQ tasks and limitations in ROMs could not be made as not all joints that are required for the performance of the task were measured.

Comparison of prevalences

The comparison of prevalences per joint calculated with the different operationalization methods showed a difference of ≥40% between the highest and lowest outcome for each movement direction. For shoulder flexion, this difference was 100% (Table 4). As expected, the prevalences from Method 3 were always lower than those from Method 2, which were subsequently always lower than those of Method 1. However,

Table 4 - Prevalence (%) of joint flexibility problems in 23 subjects per movement direction per joint according to Methods 1-4.

Method	Joints (N burned)	Shoulder (23)	Elbow (20)		Wrist (18)		Knee (24)		Ankle (10)	
	Movement direction	Flexion	Flexion	Extension	Palmar flexion	Dorsal flexion	Flexion	Extension	Plantar flexion	Dorsal flexion
1	ROM < Normative value [a]	100%	70%	45%	44%	44%	50%	50%	40%	40%
2	ROM < Normative value [a] minus 1SD	9%	15%	20%	0%	17%	8%	8%	0%	10%
3	ROM < Normative value [a] minus 2SD	0%	10%	5%	0%	0%	4%	0%	0%	0%
4	ROM < Functional ROM [b]	0%	55%	5%	0%	0%	0%	0%	0%	80%

[a] Age matched Dutch normative values of Klerks et al.[7] [b] Functional ROMs of Oosterwijk et al.[22] for shoulder and elbow; functional ROMs of Korp et al.[20] for wrist, knee, ankle.

Table 5 - Problems in functional activities scored on the 4-point Likert Scale according to the BOQ by four subjects (Method 5).

Subject	Areas burned	Functional activities		
		Walking about 300m	Turning the head to look over the shoulder	Fasting buttons
1	Back, neck dorsal, part of right upper arm, part of left upper leg	2	2	-
2	Chest, abdomen, neck ventral, part of back, part of both upper and lower arms, part of both upper legs, both hands	-	2	-
3	Both upper legs and part of left lower leg	-	-	2
4	Face, neck, part of back, both arms, hands and legs	-	-	2

On the 4-point Likert Scale a score of '1' means 'easy', '2' means 'a little hard', '3' means 'very hard' and '4' means 'can't do'.

the absolute differences between these three methods were different per movement direction (Table 4). For almost all movement directions, lower prevalences were indicated according to the functional ROM (Method 4) in comparison with those of normative ROM (Method 1) (Table 4).

Although analysing the functional problems that were experienced (Method 5) is not possible on the level of movement direction per joint, it can be concluded that the results according to Method 5 were not in line with the results according to Method 1. Four parents scoring 'a little hard' (2 on the 4-point Likert Scale) was not conform a prevalence of joint flexibility problems ranging from 40% to 100% in all of the measured movement directions.

DISCUSSION

In literature, dissatisfaction has been voiced with the most widely used operationalization of a joint flexibility problem, i.e., a problem exists if a measured ROM in a specific movement direction of a joint is one or more degrees lower than the corresponding normative ROM of healthy subjects.[9-11,14,18,19,28] Therefore, in the present study we evaluated the effect of different, alternative operationalizations of joint flexibility problems in the light of prevalences using a ROM dataset of children that were studied one to five years after burn. The results of the present study showed that the different operationalizations substantially affected prevalences on both a group and joint level.

The call to abandon the normative ROM operationalization for joint flexibility problems because of a lack of clinical relevance has a long history, especially in the literature on burn injuries,[9-11,14,18-20,28] and we agree with and support this call. In our opinion, the normative ROM operationalization (i.e., one degree or more below the normative value) of a joint flexibility problem should be abandoned as it leads to clinically irrelevant high prevalences. In the present study, we evaluated also the other normative ROM derived operationalizations (below 1SD or 2SD of normative ROM). At first, the 1SD method appeared to be a suitable option when comparing prevalence outcomes of this method with function-based outcomes on a group level. However, the results per movement direction per joint demonstrated that the 1SD method neglected the substantial differences in functional ROM per joint.

To make prevalence outcomes of joint flexibility problems relevant for evaluation of clinical care, we are convinced that the most fitting alternative is a function-related operationalization whereby two options are available, i.e., a subjective and an objective one with a combination of both most likely being superior.

Solely a subjective operationalization is not the solution for the following reasons. First, when the ROMs of multiple joints of a coordinated joint system are limited, the functional problems on a specific joint level are not detectable with a questionnaire. Second, as compensatory movements in other components of the coordinated joint system can be used to accomplish activities, the impact of a joint flexibility problem can be underestimated by the subject.[29-32] In the present study, the latter could possibly explain the difference in prevalence per group using the functional ROM-method (61%) (Method 4) and the scored functional problems (18%) (Method 5) as many functional tasks with the upper extremities can be accomplished unilaterally or with (over)use of other joints. In the long term, overuse can cause physical problems depending on how often, for how long, and at which angle these compensatory movements are used. Third, the outcome of a questionnaire is subjective and therefore, besides a limitation in joint flexibility, factors such as pain or fear to move could also influence the problems that are experienced.

Hence, we argue for an operationalization of a joint flexibility problem in terms of a functional ROM and combine this with a patient-report outcome measure. At this moment, the combined functional ROMs of Korp et al.[20] and Oosterwijk et al.[22] are the best there are. However, many activities are not yet covered including almost all dressing tasks and no distinction is made between age groups. Therefore, this still requires additional work.

Apart from the discussion regarding operationalization of joint flexibility problems, we would like to briefly draw attention to the way ROM is measured, i.e., the goniometer. It is the most commonly used, economical, and portable device to measure ROM,[33] and has been found to be reliable in patients with burns.[25] Other reports however, question its reliability,[34,35] and moreover, the minimal detectable difference is high.[25] Therefore, efforts should be made to develop a feasible, affordable, and especially more reliable instrument.

Limitations

The used data set was not large; 95 joints in 23 children assessed at various time points after burn. However, for our purpose, it was well suited because of the large range in measured ROM between the children and joints.

Scoring on the 18 items of the BOQ is not the most optimal representative for a subjective scale to indicate flexibility problems in ADL. There are other scales more specifically designed for this. However, as the present data were part of a more comprehensive study in which many measures were already taken, the most relevant selection of the available data was used.

As previously mentioned, the combined functional ROMs of Korp et al.[20] and Oosterwijk et al.[22] are the best that are currently available, however, many activities are not yet addressed including almost all dressing tasks, and no distinction is made between age groups. Studies on functional ROM in children are still minimal and comprise only a limited number of tasks.[1,36-39] It is possible that the functional ROM for children differs from that of adults due to postural differences and differences in ADL tasks. Furthermore, it must be mentioned that subjects with a ROM lower than the functional ROM could still be able to complete ADL tasks with compensatory movements.

Further research

The essence of the present study is to encourage an internationally accepted clinically relevant operationalization for joint flexibility problems. Research aiming at such operationalization could include a Delphi-study with experts of different burn centers, orthopedic surgeons, physiotherapists and occupational therapists. Besides, if functional ROM is advocated, future research should focus on what tasks cover full ADL for different populations, for instance children, adults and elderly.

CONCLUSION

The outcomes of the prevalence of joint flexibility problems for the entire group and per movement direction differ substantially depending on the operationalization of joint flexibility problems that are used. This finding leads to the recommendation that international consensus is required on disregarding normative ROM-based operationalizations of joint flexibility problems and adopting a new function-related operationalization.

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REFERENCES

1. Palmieri TL, Petuskey K, Bagley A, Takashiba S, Greenhalgh DG, Rab GT. Alterations in functional movement after axillary burn scar contracture: a motion analysis study. J Burn Care Rehabil. 2003;24:104-8.
2. Leblebici B, Adam M, Bagis S, Tarim AM, Noyan T, Akman MN, et al. Quality of life after burn injury: the impact of joint contracture. J Burn Care Res. 2006;27:864-8.
3. Fischer U, Müller M, Strobl R, Bartoszek G, Meyer G, Grill E. Examining functioning and contextual factors in individuals with joint contractures from the health professional perspective using the ICF: an international internet-based qualitative expert survey. Rehabil Nurs. 2016;41:170 -8.
4. Fergusson D, Hutton B, Drodge A. The epidemiology of major joint contractures: a systematic review of the literature. Clin Orthop Relat Res. 2007;456:22-9.
5. Magee DJ. Orthopedic physical assessment. 5th ed. St Louis: Saunders Elsevier; 2008.
6. American Academy of Orthopaedic Surgeons. Joint motion: methods of measuring and recording. Chicago: AAOS; 1965.
7. Klerks M, Niemeijer A, Jelsma D, Smits-Engelsman B. Defining hyper and hypo mobility for passive joint motion in children aged 3-16 years [abstract and poster]. Physiotherapy 2011. Heading Professional Practice: Paediatrics: Musculoskeletal. [Last accessed 7 February 2018] http://www. abstractstosubmit. com/wpt2011/abstracts/.
8. Kumar S, Sharma R, Gulati D, Dhammi IK, Aggarwal AN. Normal range of motion of hip and ankle in Indian population. Acta Orthop Traumatol Turc. 2011;45:421 -4.
9. Schneider JC, Holavanahalli R, Helm P, Goldstein R, Kowalske K. Contractures in burn injury: defining the problem. J Burn Care Res. 2006;27:508 -14.
10. Goverman J, Mathews K, Goldstein R, Holavanahalli R, Kowalske K, Esselman P, et al. Adult contractures in burn injury: a burn model system national database study. J Burn Care Res. 2017;38:e328 -36.
11. Goverman J, Mathews K, Goldstein R, Holavanahalli R, Kowalske K, Esselman P, et al. Pediatric contractures in burn injury: a burn model system national database study. J Burn Care Res. 2017;38:e192-9.
12. Gorga D, Johnson J, Bentley A, Silverberg R, Glassman M, Madden M, et al. The physical, functional, and developmental outcome of pediatric burn survivors from 1 to 12 months postinjury. J Burn Care Rehabil. 1999;20:171-8.
13. Huang TT, Blackwell SJ, Lewis SR. Ten years of experience in managing patients with burn 379 contractures of axilla, elbow, wrist, and knee joints. Plast Reconstr Surg. 1978;61: 70-6.
14. Godleski M, Lee AF, Goverman J, Herndon DN, Suman OE, Kowalske KJ, et al. Quantifying contracture severity at hospital discharge in adults: a burn model system national database study. J Burn Care Res. 2018;39:604-11.
15. Clavet H, Hébert PC, Fergusson D, Doucette S, Trudel G. Joint contracture following prolonged stay in the intensive care unit. CMAJ. 2008;178:691-7.
16. Oosterwijk AM, Mouton LJ, Schouten H, Disseldorp LM, van der Schans CP, Nieuwenhuis MK. Prevalence of scar contractures after burn: a systematic review. Burns. 2017;43:41 -9.
17. de Onis M, Onyango AW, Borghi E, Siyam A, Nishida C, Siekmann J. Development of a WHO growth reference for school-aged children and adolescents. Bull World Health Organ. 2007;85:660-7.

18. Dobbs ER, Curreri PW. Burns analysis of results of physical therapy in 681 patients. J Trauma. 1972;12:242-8.
19. Schneider JC, Holavanahalli R, Helm P, O'Neil C, Goldstein R, Kowalske K. Contractures in burn injury part II: investigating joints of the hand. J Burn Care Res. 2008;29:606-13.
20. Korp K, Richard R, Hawkins D. Refining the idiom "functional range of motion" related to burn recovery. J Burn Care Res. 2015;36:e136-45.
21. Gates DH, Walters LS, Cowley J, Wilken JM, Resnik L. Range of motion requirements for upper-limb activities of daily living. Am J Occup Ther. 2016;70:1-10.
22. Oosterwijk AM, Nieuwenhuis MK, van der Schans CP, Mouton LJ. Shoulder and elbow range of motion for the performance of activities of daily living: a systematic review. Physiother Theory Pract. 2018;29:1-28.
23. Elm von E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP, STROBE initiative. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. Lancet. 2007;370:1453-7.
24. Disseldorp LM, Mouton LJ, Takken T, Van Brussel M, Beerthuizen GI, Van der Woude LH, et al. Design of a cross-sectional study on physical fitness and physical activity in children and adolescents after burn injury. BMC Pediatr. 2012;12:195.
25. Edgar D, Finlay V, Wu A, Wood F. Goniometry and linear assessments to monitor movement outcomes: are they reliable tools in burn survivors? Burns. 2009;35:58-62.
26. Daltroy LH, Liang MH, Phillips CB, Daugherty MB, Hinson M, Jenkins M, et al. American Burn Association/Shriners Hospitals for Children burn outcome questionnaire: construction and psychometric properties. J Burn Care Rehabil. 2000;21:29-39.
27. van Baar ME, Essink-Bot ML, Oen IM, Dokter J, Boxma H, Hinson MI, et al. Reliability and validity of the dutch version of the american burn Association/Shriners hospital for children burn outcome questionnaire (5-18 years of age). J Burn Care Res. 2006;27:790-802.
28. Gangemi EN, Gregori D, Berchialla P, Zingarelli E, Cairo M, Bollero D, et al. Epidemiology and risk factors for pathologic scarring after burn wounds. Arch Facial Plast Surg. 2008;10:93-102.
29. de Groot JH, Angulo SM, Meskers CG, van der Heijden-Maessen HC, Arendzen JH. Reduced elbow mobility affects the flexion or extension domain in activities of daily living. Clin Biomech (Bristol, Avon). 2011;26:713-7.
30. Mell AG, Childress BL, Hughes RE. The effect of wearing a wrist splint on shoulder kinematics during object manipulation. Arch Phys Med Rehabil. 2005;86:1661-4.
31. Trehan SK, Wolff AL, Gibbons M, Hillstrom HJ, Daluiski A. The effect of simulated elbow contracture on temporal and distance gait parameters. Gait Posture. 2015;41:791-4.
32. Veeger HE, Magermans DJ, Nagels J, Chadwick EK, van der Helm FC. A kinematical analysis of the shoulder after arthroplasty during a hair combing task. Clin Biomech (Bristol, Avon). 2006;21(Suppl 1):S39-44.
33. Lea RD, Gerhardt JJ. Range-of-motion measurements. J Bone Joint Surg Am. 1995;77:784-98.
34. van Trijffel E, van de Pol RJ, Oostendorp RA, Lucas C. Inter-rater reliability for measurement of passive physiological movements in lower extremity joints is generally low: a systematic review. J Physiother. 2010;56:223-35.
35. van de Pol RJ, van Trijffel E, Lucas C. Inter-rater reliability for measurement of

passive physiological range of motion of upper extremity joints is better if instruments are used: a systematic review. J Physiother. 2010;56:7-17.
36. Mosqueda T, James MA, Petuskey K, Bagley A, Abdala E, Rab G. Kinematic assessment of the upper extremity in brachial plexus birth palsy. J Pediatr Orthop. 2004;24: 695-9.
37. Petuskey K, Bagley A, Abdala E, James MA, Rab G. Upper extremity kinematics during functional activities: three-dimensional studies in a normal pediatric population. Gait Posture. 2007;25:573-9.
38. Reid S, Elliott C, Alderson J, Lloyd D, Elliott B. Repeatability of upper limb kinematics for children with and without cerebral palsy. Gait Posture. 2010;32:10-7.
39. Klotz MCM, van Drongelen S, Rettig O, Wenger P, Gantz S, Dreher T, et al. Motion analysis of the upper extremity in children with unilateral cerebral palsy - an assessment of six daily tasks. Res Dev Disabil. 2014;35:2950-7.

6

Course of prevalence of scar contractures limiting function: a preliminairy study in children and adolescents after burns

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ABSTRACT

Background: Scar contracture is a well-known sequela of burns that is specifically relevant as it may limit function. Reports regarding the course of scar contractures, however, are scarce and, moreover, not focused on function. This study describes the course of prevalence of scar contractures that limit function in children and adolescents after burns.

Method: Range of motion (ROM) of extremity joints of 20 children and adolescents after burns were assessed at discharge (T0) and at six weeks (T1), three months (T2), and six months (T3) after discharge. A scar contracture limiting function was defined as a measured ROM lower than the functional ROM, i.e., ROM used to perform daily activities by unimpaired subjects.

Results: At discharge (T0), 89.5% of the subjects had one or more scar contractures that limited function. Six months later (T3), this prevalence was 76.5%. At discharge (T0), less function limiting scar contractures were found for the upper extremity (29.7%) than the lower extremity (53.3%). Over time, prevalence of contractures in both extremities fluctuated between 22% and 35%.

Conclusions: The majority of children and adolescents (13/17) still had scar contractures limiting function six months after discharge (T3). Substantial longitudinal studies over a longer period of time are needed to increase our knowledge on the course of these scar contractures in order to support improvements in burn care.

Trial registration: The study is approved by the Regional Committee for Patient-Oriented Research Leeuwarden in the Netherlands (NL45917.099.13).

INTRODUCTION

Scar contractures are the pathological outcome of excessive scarring and ongoing contraction and are a well-known complication after burns.[1-3] When contracting scar tissue is across or adjacent to a joint, this may result in loss of range of motion (ROM) in one or more movement directions of that joint.[1,3-6] This can subsequently cause problems in the performance of activities concerning daily living (ADL), school, work, sports, and leisure time and, therefore, poses a threat to quality of life in the long term.[2,7]

One of the goals of burn care rehabilitation is to reduce scar contractures so that these do not influence functioning in daily life. Studies on the prevalence of scar contractures and its course form the basis for evaluation and improvement of burn care. Until now, however, only limited data on the prevalence of scar contractures in adults is available, and this is even less in children[8] whereas, in children, the risk to develop contractures is higher.[8,9] Two studies assessed ROM only at discharge in children with major burns (according to ABA criteria) and concluded that the prevalence of one or more scar contractures was 23%[10] and 54%.[11] Outcomes showed that contractures primarily occurred in the upper extremity joints. One other study[12] concerned long term outcome and measured ROM in adults who had sustained a minor burn injury (mean total body surface area burned (TBSA) 8.2%) in childhood (median time since injury 13.6 years; mean age at time of injury: 5.3 years). This study reported a prevalence of one or more scar contractures of 18%, and a predisposition for scar contractures in the joints of the upper extremity was also found. There is only one longitudinal study of children[13] reporting on the course of prevalence of scar contractures up to 12 months after injury. In these young children (mean age 2.3 years) with minor burns (mean TBSA 6%), a prevalence of one or more scar contractures of 4%, 2%, and 2% was found at one, six, and 12 months after injury, respectively. More studies on the prevalence of scar contractures and its course focusing on a varied population are needed, especially longitudinal studies.

Not only are limited data available on the prevalence and course of scar contractures in children, there is also the question of how a scar contracture is defined as dissatisfaction is being voiced with the norm-based operationalization of scar contractures that has generally been used up till now.[1,14-17] Like almost all earlier studies on prevalence of scar contractures,[8] the four studies described above operationalized a scar contracture by comparing the measured ROM of a specific joint and movement direction to its norm value, i.e., the maximal ROM of healthy subjects of a specific movement direction of a joint. However, the significance of scar contractures lies in their limiting effects on function, including the performance of daily tasks. This means that the use of norm ROM is only relevant if it is approximate to the ROM that is necessary for ADL. Whereas for some joints and movement directions this is indeed the case, for others, there is a large discrepancy between norm ROM and the ROM that is necessary for ADL. For example, for elbow flexion, the ROM necessary to perform ADL tasks and norm ROM are approximately the same (152° vs. 154°, respectively) while the ROM necessary to perform ADL tasks for shoulder flexion is 142°, and norm ROM is 180°.[17,18] Therefore, to gain insight into the extent of the problems that scar contractures cause and thus ways to improve its outcome, it makes more sense to determine if a scar contracture limits function.[16] To achieve this, function-based ROM cut-off points can be used,[17,19] i.e., compare measured ROM of a specific joint and movement direction to function-based ROM cut-off values for that specific joint and movement direction (instead of its norm value). We recently explicated this function-based operationalization of scar contracture in a cross-sectional study in children and adolescents one to five years after a burn injury.[16] The aim of the present study is to gain a first insight into the extent of the problems of scar contractures in children and adolescents after burns from discharge up to six months after discharge by applying the function-based operationalization of scar contracture.

METHODS

Study design and subjects

Data originated from a multi-center prospective cohort study,[20] that had been approved by the Regional Committee for Patient-Oriented Research Leeuwarden (in Dutch: Regionale Toetsingscommissie Patiëntgebonden Onderzoek - RTPO, number NL45917.099.13). This study comprised children and adolescents (6-18 years) who were admitted to one of the three Dutch Burn Centers between May 2014 and February 2017 with burns involving >5% TBSA, a length of stay of more than two weeks, or both. Extensive (pre-existing) comorbidity, (mental) disabilities, insufficient Dutch language proficiency, and contra-indications for maximal exercise testing were criteria for exclusion. All children received standard care according to the treatment views of the Dutch Working Group on Burn Rehabilitation. Physical rehabilitation interventions started shortly after admission to prevent contractures including anticontracture positioning, active, active-assisted and passive ROM exercises, mobilization out of bed and pressure garments. Written informed consent was provided by all of the parents (or legal representatives) as well as by participants aged ≥12 years before enrolment; for participants aged 18 parental informed consent was not required. A total of 53 children and adolescents were eligible, and 24 of them were included. Comparison of the 24 subjects and 25 non-subjects showed no significant differences with regard to the distribution of gender (p = .858), mean age at burn injury (p = .778), extent of burn (p = .600), length of hospital stay (p = .803), and number of surgeries (p = .907).[20] The total prospective study comprised the assessment of exercise capacity, body composition, muscular strength, joint range of motion, physical activity and sedentary behavior, perceived fatigue, and health-related quality of life. Assessments were done in combination with regular clinical follow-up at the burn center where the follow-up visits took place, usually the center of admission. Measurements were performed by a physical therapist or a researcher from the burn center. Time of assessment was at discharge (T0) and at six weeks (T1), three months (T2), and six months (T3) after discharge. As this study is part of a larger one, including variables like exercise capacity, time after discharge was chosen as starting point. In view of the fact that assessments were done in combination with clinical follow-up visits, time after discharge is not exact, but subject to a certain variability. For the present study, ROM data of 20 of the 24 subjects were available for analysis as four subjects did not have burns across or adjacent to joints of the upper or lower extremity (Figure 1). Subject and burn characteristics were obtained from the National Dutch Burn Repository including age, gender, extent and depth of burn, location of burn, length of stay at the hospital, and information regarding surgical intervention. As time after burn reflects scar maturation better, data on time after burn are given as well as those on time after discharge (Table 1).

Range of motion measurements

ROM data of joints with burns across or adjacent to that joint were used. Being adjacent to a joint was defined as a burn at a maximum distance of 1/3 of the length of the adjoining body part/limb. Passive ROM was measured in degrees with a lateral goniometer (Gollehon extendable goniometer 01135, Lafayette Instrument, Lafayette, U.S.A.) according to the standardized protocol of Klerks et al. [18] This protocol is based on osteokinematics and describes the starting position of the patient, passive movement to perform, placement of the goniometer and notation of angles achieved. Joints and movement directions that were measured included: shoulder flexion, elbow flexion and extension, wrist palmar and dorsal flexion, knee flexion and extension, and ankle plantar and dorsal flexion.

Outcome analysis

A scar contracture limiting daily function was defined as a measured ROM lower than the functional ROM, i.e., the ROM that is necessary for that specific joint and movement direction to perform daily activities by unimpaired subjects. These functional ROMs were taken from Oosterwijk et al.[17] for the movement directions of shoulder and elbow and from Korp et al.[19] for those of wrist, knee, and ankle (Table 2).

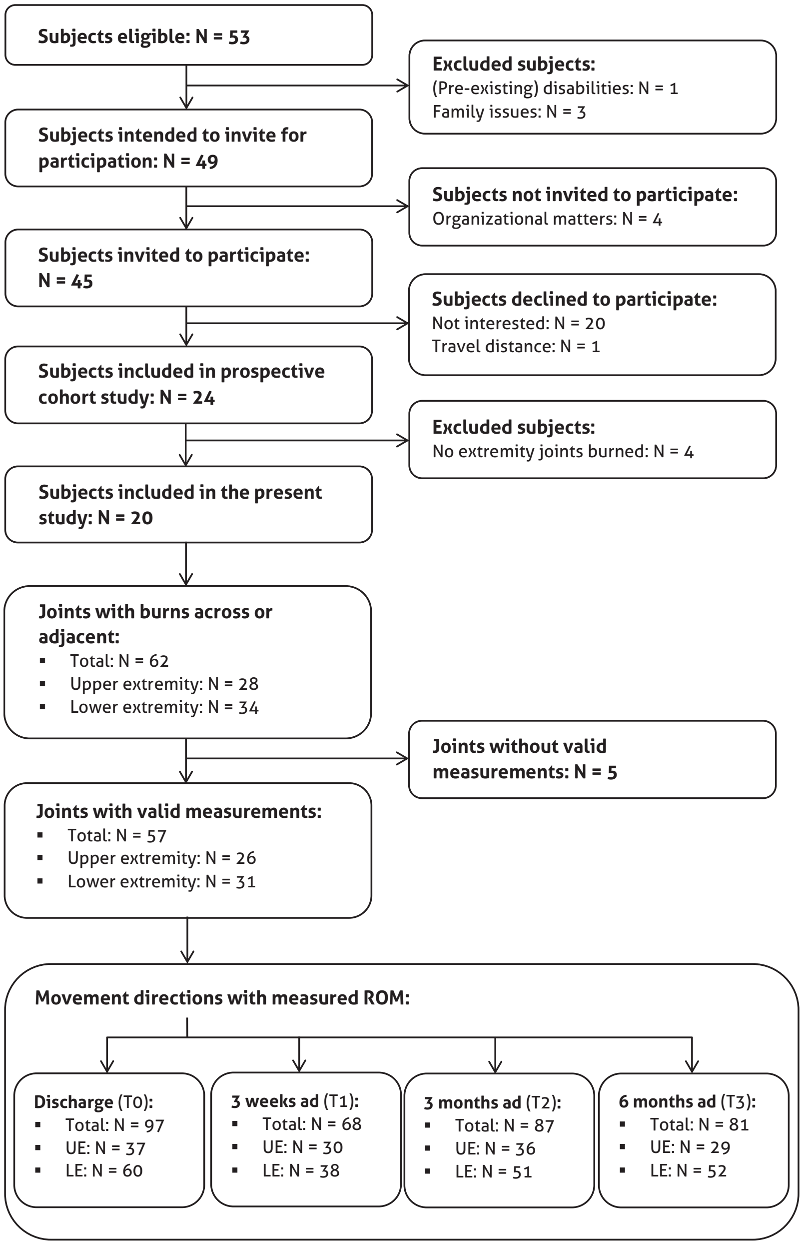

Figure 1 - Flow diagram resulting in number of valid ROM measurements for the total movement directions and per upper and lower extremity. UE: upper extremity; LE: lower extremity; ad: after discharge.

Table 1 - Subject characteristics, burn characteristics and times of assessments.

	N	Percentage	Mean ± SD	Mode	Range
Subjects characteristics	20				
Age at burn injury (years)			12.3 ± 3.3		7 - 18
Male subjects	14	70%			
Burn characteristics					
% TBSA involved			12.6 ± 9.3		0.1 - 34
< 10%	11	55%			
≥ 10%, ≤ 20%	4	20%			
> 20%	5	25%			
Full thickness burns (%TBSA)	8	40%	1.5 ± 2.8		0 - 10.5
Subjects with arms involvement	12	60%			
Subjects with legs involvement	16	80%			
Time from burn to hospitalization (days)			0.4 ± 1.1		0 - 5
Length of hospital stay (days)			23.9 ± 15.6		12 - 66
≤ 2 weeks	5	25%			
> 2 weeks, < 4 weeks	10	50%			
≥ 4 weeks	5	25%			
Children with surgery [a]	15	75%			
Number of surgeries [a]			1.5 ± 1.5	1	0 - 5
Children with reconstructive surgery [b]	2	10%			
Number of reconstructive surgeries [b]			0.1 ± 0.3	0	0 - 1
Times of assessments after discharge					
T0: 'Discharge' (days)			4.3 ± 3.5		-1 - 10
T1: '6 weeks after discharge' (days)			47.4 ± 6.8		37 - 63
T2: '3 months after discharge' (days)			97.3 ± 15.1		74 - 140
T4: '6 months after discharge' (days)			185.9 ± 21.9		131 - 216
Times of assessments after burn					
T0: 'Discharge' (days)			28.5 ± 15.0		16 - 69
T1: '6 weeks after discharge' (days)			71.2 ± 16.5		56 - 123
T2: '3 months after discharge' (days)			122.3 ± 22.5		86 - 172
T3: '6 months after discharge' (days)			211.1 ± 24.9		185 - 277

N = number; %TBSA = percentage of total body surface area affected by burns. [a] Surgery as part of acute care, i.e., surgery aimed at wound closure. [b] Children admitted for reconstructive surgery during study.

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Table 2 - Functional ROM values needed for the performance of daily tasks per movement direction of a joint in degrees.

	Shoulder Flexion	Elbow Flexion	Elbow Extension[b]	Wrist Palmair Flexion	Wrist Dorsal Flexion
Functional ROM [a]	142°	152°	-1°	54°	63°

Table 2 - *Continued*

	Knee Flexion	Knee Extension[b]	Ankle Plantair Flexion	Ankle Dorsal Flexion
Functional ROM [a]	138°	0°	32°	36°

[a] Functional ROMs of Oosterwijk et al.[17] for shoulder and elbow; Functional ROMs of Korp et al.[19] for wrist, knee, ankle. [b] A positive number for extension means hyperextension; when the zero-position cannot be performed (elbow or knee completely straight), the limitation is described with a minus-sign.

The prevalence of scar contractures that limit daily function was calculated at each time point of assessment. Prevalence was calculated as the percentage of subjects with one or more scar contractures that limited function. To differentiate between the upper and lower extremities, prevalence was also calculated as the percentage of scar contractures limiting function per upper extremity movement directions (shoulder flexion, elbow flexion and extension, wrist palmar and dorsal flexion) as well as lower extremity movement directions (knee flexion and extension, ankle plantar and dorsal flexion). Also the prevalence was calculated of connecting joints in which one or more movement directions had a contracture that limited function in both, or all three joints (shoulder-elbow-wrist, shoulder-elbow, elbow-wrist, knee-ankle).

Statistical analysis

To evaluate whether more function limiting upper extremity movements directions compared to function limiting lower extremity movement directions are determined, confidence intervals are compared and Chi-Square analyses are conducted per time of assessment. An alpha-level of 5% was adopted, but adjusted towards $p = 0.0125$ as suggested by Bonferroni to prevent capitalization on chance due to multiple testing.

RESULTS

Measured subjects and movement directions

In the 20 subjects, there were 62 joints (28 upper extremity, 34 lower extremity) with burns across or adjacent to that joint (Figure 1). ROM data of 57 joints (26 upper extremity, 31 lower extremity) were used to calculate the prevalence. Per time point of assessment, the number of subjects that were assessed varied due to subjects missing follow-up assessments or not wanting to cooperate (number of subjects assessed at discharge (T0): 19; six weeks after discharge (T1): 16; three months after discharge (T2): 17; six months after discharge (T3): 17). Also, the number of movement directions measured, varied (Figure 1 and Table 3).

Course of prevalence of scar contractures that limit function

The percentage of subjects with one or more contractures that limit function was 89.5% at discharge (T0), 81.3% at six weeks (T1), 82.4% at three months (T2) and 76.5% at six months (T3) after discharge.

Table 3 - Prevalence of scar contractures limiting function per movement direction per time of assessment.

Movement direction	Time of assessment							
	Discharge (T0)		6 weeks after discharge (T1)		3 months after discharge (T2)		6 months after discharge (T3)	
	N	Limited function	N	Limited function	N	Limited function	N	Limited function
Total	97	43 (44.3%)	68	20 (29.4%)	87	21 (21.4%)	81	25 (30.8%)
Upper extremity	37	11 (29.7%)	30	10 (33.3%)	36	8 (22.2%)	29	7 (24.1%)
Shoulder flexion	7	2 (28.6%)	6	1 (16.7%)	6	1 (16.7%)	5	1 (20.0%)
Elbow flexion	9	7 (77.8%)	7	7 (100.0%)	7	6 (85.7%)	6	4 (66.7%)
Elbow extension	9	2 (22.2%)	7	2 (28.6%)	7	0 (0.0%)	6	1 (16.7%)
Wrist palmar flexion	6	0 (0.0%)	5	0 (0.0%)	8	0 (0.0%)	6	0 (0.0%)
Wrist dorsal flexion	6	0 (0.0%)	5	0 (0.0%)	8	1 (12.5%)	6	1 (16.7%)
Lower extremity	60	32 (53.3%)	38	10 (26.3%)	51	13 (25.5%)	52	18 (34.6%)
Knee flexion	18	15 (83.3%)	12	4 (33.3%)	16	3 (18.8%)	17	6 (35.3%)
Knee extension	18	3 (16.7%)	12	0 (0.0%)	17	0 (0.0%)	17	2 (11.8%)
Ankle plantar flexion	12	2 (16.7%)	7	0 (0.0%)	9	1 (11.1%)	9	1 (11.1%)
Ankle dorsal flexion	12	12 (100.0%)	7	6 (85.7%)	9	9 (100.0%)	9	9 (100.0%)

N: number of measurements per movement direction.

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Table 3 shows that percentages of limitations in the upper and lower extremity are equally distributed through time. Although it appears as if lower extremity is more often affected by limitations at discharge (T0) (Table 3 and Figures 2 and 3), the difference between upper extremity and lower extremity is not significant (95% CI: 15.0-44.4 and 95% CI: 40.7-65.9 for upper extremity and lower extremity, respectively, with non-adjusted $p = .023$, adjusted $p = .092$). The high prevalence of these contractures were primarily caused by limitations in elbow flexion, knee flexion, and ankle dorsal flexion. From six weeks (T1) to six months (T3) after discharge, the prevalence for upper extremity scar contractures that limit function was rather stable whereby the number in the elbow flexion direction remained extensive. In contrast, prevalence for the lower extremity almost halved at six weeks (T1) after discharge mainly due to a large decrease in the number of contractures that limit function in the knee flexion direction. Three months after discharge (T2), the prevalence for lower extremity scar contractures that limit function was rather stable but slightly increased at six months after discharge (T3). The number of function limiting contractures in the ankle dorsal flexion direction remained extensive over time (Table 3 and Figures 2 and 3). Differences between functional limitations in the upper and lower extremity were also not significant at other time points (T1: 95% CI UE: 16.5-50.2 and 95% CI LE: 12.3-40.3, with non-adjusted $p = .528$, adjusted $p = 1.000$; T2: 95% CI UE: 8.6-35.8 and 95% CI LE: 13.5-37.5, with non-adjusted $p = .726$, adjusted $p = 1.000$; T3: 95% CI UE: 8.6-39.7 and 95% CI LE: 21.7-47.5, with non-adjusted $p = .328$, adjusted $p = 1.000$).

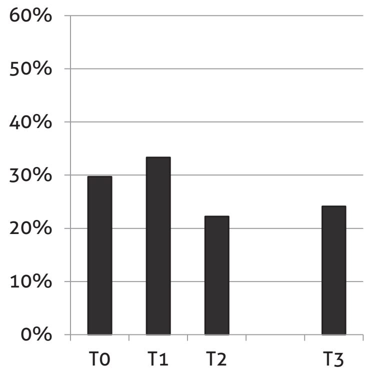

Figure 2 - Course of prevalence of scar contractures that limit function for upper extremity joints. T0: discharge; T1: six weeks after discharge; T2: three months after discharge; T3: six months after discharge.

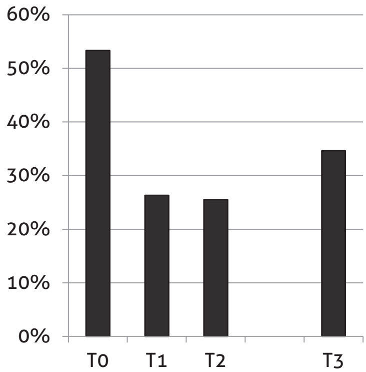

Figure 3 - Course of prevalence of scar contractures that limit function for lower extremity joints. T0: discharge; T1: six weeks after discharge; T2: three months after discharge; T3: six months after discharge.

Thirteen of the 20 children had in total 22 connecting joint combinations that were burned. Eight of these 13 children (61.5%) had a connecting joint combination whereby multiple joints were functional limited in one or more movement directions: at discharge (T0) seven children with eight joint combinations, at 6 weeks (T1) and 3 months (T2) after discharge one child with one joint combination, at 6 months after discharge (T3) two children with four joint combinations (Table 4).

Table 4 - Joint combinations with contractures limiting function in one or more movement directions of both, or all three, joints.

Joint combinations	Total[a]	Discharge (T0)		6 weeks after discharge (T1)		3 months after discharge (T2)		6 months after discharge (T3)	
		Limited function		Limited function		Limited function		Limited function	
Shoulder - Elbow	7	1	(14.3%)	1	(14.3%)	1	(14.3%)	1	(14.3%)
Elbow - Wrist	4	0	(0.0%)	0	(0.0%)	0	(0.0%)	1	(25.0%)
Shoulder - Elbow - Wrist	3	0	(0.0%)	0	(0.0%)	0	(0.0%)	1	(33.3%)
Knee - Ankle	8	7	(87.5%)	0	(0.0%)	0	(0.0%)	1	(12.5%)

[a] Number of connecting joint combinations with burn in both, or all three, joints.

DISCUSSION

The results of the present study showed that the prevalence of subjects with one or more contractures that limit function was high at discharge (T0) (89.5%) and remained substantial during the initial six months after discharge (T1; T2; T3) with only slight fluctuations over time (81.3%; 82.4%; 76.5%). At discharge (T0), a higher prevalence of lower extremity contractures than upper extremity contractures that limit function was determined (53.3% versus 29.7%). Over time, the prevalence of contractures in both extremities fluctuated between 22% and 35%. The prevalence of upper and lower extremity contractures that limit function were mainly caused by the limitations in the elbow flexion, knee flexion, and ankle dorsal flexion direction.

Until now, no longitudinal study exists concerning the prevalence of scar contractures using a function-based operationalization of contractures. This means that no direct comparison of the present results with earlier results is possible. However, the function-based operationalization was employed in our earlier study with a cross sectional design. In this study, scar contractures that limit function were identified in 23 Dutch children and adolescents one to five years after burn (mean age at injury: 7.5 years, mean TBSA: 18.2%) who had usual care.[16] In 61% of the subjects, one or more of these contractures was found at the time of assessment. The present results are in accordance with this earlier study, i.e., the prevalence remains high over time. In both of these studies, the same joints, i.e., the elbow, knee, and ankle, were found to be most affected by scar contractures with functional limitations.

The only earlier longitudinal study on scar contractures in children and adolescents used the, until now most common, norm-based operationalization of contractures.[13] This study reported very low prevalences of contractures, i.e., 4%, 2%, and 2% of the subjects had one or more contractures at one, six and twelve months after injury, respectively. Furthermore, the number of lower extremity contractures was ascertained to be higher at one month after injury than at six and twelve months after injury whereas no upper extremity contractures were found at any of the assessment times. Although the same trend for lower extremity contractures was determined as that in the present study, no conclusions can be drawn due to the different operationalization and population (much younger and less extensive burns).

That scar contractures limit function over the initial six months after discharge in children and adolescents is high might be caused by a combination of factors. At discharge, the high prevalence and corresponding lower measured ROMs can be influenced by pain, fear to move, muscular defense, edema, and a patient's compliance.[21,22] It may even be questioned whether it is correct to be speaking of scar contractures at that time as there will not yet be much pathologic scar tissue that limits ROM. Up to six months after discharge, a lower ROM can be due to the gradual increase in strength of the scar during the maturation phase of the burn healing progress.[23] The latter is supported by the finding that, between three and six months after burn, the pliability of scars decreases and thickness increases.[24] Even with time, an increment of scar contractures can be expected, particularly in children as their growth can exceed the capacity for scars to grow.[25] Despite these different influences on ROM over time, measuring until or at discharge is done most often,[1,10,11,15,22] however, these results have little predictive value in the long term.[21] Therefore, we recommend analyzing the functional complications of scar contractures over a period of at least twelve months after injury and preferably beyond.

On a joint level, several other factors might have influenced the found prevalence of scar contractures that limit function. First, every joint is susceptible to contractures but, for various joints and movement directions, contractures are relatively common. The following directions are often limited in movement: flexion and abduction of the shoulder, extension of the elbow, and extension of the knee.[26] Probable reasons that account for the high incidence that are encountered are the wide range of motion and asynchronous muscular control in combination with a high vulnerability to burn injuries.[26] Second, per extremity, the amount of stretch and exercise differs over time. During hospitalization, legs are used minimally because of patients often being confined to bed. After discharge, bilateral use of the legs is necessary for walking and other daily activities which causes stretch at the scars and advances functional recovery.[21,27,28] For the arm, during and after hospitalization, a large part of the ADL tasks can be executed by using the unaffected arm or with compensatory movements of the affected arm and/or thorax. Consequently, subjects are less challenged to naturally stretch upper extremity scars. In addition, resting and general use of the upper extremity involves the direction of contracture whereas activities involving the lower extremity are opposite to contracture formation.

In clinical practice, the extent of the problem of ROM loss in light of functionality will be different per person. No or less functional problems can be experienced when compensatory movements are used for the performance of tasks. However, what the consequences of compensatory movements are in the long term is not clear. Furthermore, per age category (children, adults, elderly), what constitutes their activities of daily living will differ and, therefore, so will the corresponding cut-off points for functional ROM. A clear overview of ADL tasks is needed per age category to indicate the basic extent of the problem of scar contractures and to evaluate the effectiveness of treatment on a group level. On an individual level, questionnaires such as the Canadian Occupational Performance Measure (COPM)[29] or Patient Specific Functional Scale (PSFS)[30] can be used to identify performance problems that are specific for that individual with, e.g., leisure, work, and sport activities.

Limitations

First, only a small ROM dataset of 57 joints measured for 20 children and adolescents was used in the present preliminary study. The non-response analysis did show that this sample is representative for all children and adolescents that were admitted to the three Dutch Burn Centers during the inclusion period of almost three years. However, due to this limitation, we did not analyze more specific associations between how function limited scar contractures evolved over time and possible risk factors on joint level (%TBSA around the affected joint, depth of burn, etiology) or subject level (%TBSA total, age, gender, length of stay at the hospital, physical activity, and sedentary behavior) in the present study.

Second, whereas we strongly recommend the use of a function-based operationalization to identify scar contractures that limit function and used the best data concerning functional ROM that is currently available,[17,19] there are some shortcomings. The tasks used underlying these presently available functional ROM data mainly concern adult tasks. Functional ROM in children has only been evaluated in a few studies and for a limited number of tasks.[31-35] Due to postural differences and differences in ADL tasks, it is possible that the functional ROM for children and adolescents differs from that of adults or older individuals. Moreover, a significant number of tasks has been studied, however, they do not yet represent all essential ADL tasks. For example, activities such as dressing are not included in the presently available functional ROMs.

Third, the functional ROM values used in the present study were determined during the performance of ADL tasks and therefore represent active ROM. The data collected however, concern passive ROM measurements. Generally, active ROM is a bit lower than passive ROM, meaning that the present prevalence results on contractures might be a small underestimation of the actual prevalence. On the other hand, there may also be an small overestimation of the actual prevalence based on the fact that in some ADL tasks ROM will have been measured in a loaded condition. In a loaded condition the measured ROM can be higher than passive ROM because of added body mass. The latter is more likely to occur in tasks where extreme ROMs of the lower extremity joints are needed, e.g., ankle dorsal flexion during stair descent.[36] We recommend to measure active ROM to have best comparison with functional ROM.

Fourth, for ROM assessments it would be better to choose time after burn as start of measurement instead of time after discharge.

Further research

The present preliminary longitudinal study reported the course of prevalence of scar contractures in light of function. Further research should first focus on the optimization of the functional ROMs by measuring the required ROM for the performance of more ADL tasks in unimpaired subjects; also in different age groups including children and adolescents. When functional ROMs are optimized, data of existing studies[1,10-13,21,22] can be reanalyzed in order to come to conclusions regarding functional loss of motion and influencing risk factors. Large and well-designed longitudinal studies are indicated that measure active ROM in children and adolescents after burns and analyze the course of prevalence of scar contractures that limit function preferably with a study period until at least the end of scar maturation. In addition, analyzing associations between evolvement of function limited scar contractures over time and possible risk factors, including extent of burn and influence of contractures of connecting joints, are recommended.

CONCLUSION

Scar contractures are a substantial problem in children and adolescents receive burns as 76.5% of the subjects still have a functional limitation in one or more movement directions six months after discharge. Substantial, well-designed longitudinal (inter) national studies are needed that investigate the course of prevalence of scar contracture after burns in children and adolescents, especially in light of functionality for a longer period of time. To accomplish this, first, more research is of benefit to ascertain functional ROM values for the performance of representative daily tasks in different age groups.

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Declarations of interest

None.

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REFERENCES

1. Schneider JC, Holavanahalli R, Helm P, Goldstein R, Kowalske K. Contractures in burn injury: defining the problem. J Burn Care Res. 2006;27:508-14.
2. Leblebici B, Adam M, Bagis S, Tarim AM, Noyan T, Akman MN, et al. Quality of life after burn injury: the impact of joint contracture. J Burn Care Res. 2006;27:864-8.
3. Schouten HJ, Nieuwenhuis MK, van Zuijlen PP. A review on static splinting therapy to prevent burn scar contracture: do clinical and experimental data warrant its clinical application? Burns. 2012;38:19-25.
4. Parry I, Walker K, Niszczak J, Palmieri T, Greenhalgh D. Methods and tools used for the measurement of burn scar contracture. J Burn Care Res. 2010;31:888-903.
5. Richard R, Baryza MJ, Carr JA, Dewey WS, Dougherty ME, Forbes-Duchart L, et al. Burn rehabilitation and research: proceedings of a consensus summit. J Burn Care Res. 2009;30:543-73.
6. Richard RL, Lester ME, Miller SF, Bailey JK, Hedman TL, Dewey WS, et al. Identification of cutaneous functional units related to burn scar contracture development. J Burn Care Res. 2009;30:625-31.
7. Heise M, Müller M, Fisher U, Grill E. Quality of life in older individuals with joint contractures in geriatric care settings. Qual Life Res. 2016;25:2269-81.
8. Oosterwijk AM, Mouton LJ, Schouten H, Disseldorp LM, van der Schans CP, Nieuwenhuis MK, et al. Prevalence of scar contractures after burn: a systematic review. Burns. 2017;43:41-9.
9. Kraemer MD, Jones T, Deitch EA. Burn contractures: incidence, predisposing factors, and results of surgical therapy. J Burn Care Rehabil. 1988;9:261-5.
10. Goverman J, Mathews K, Goldstein R, Holavanahalli R, Kowalske K, Esselman P, et al. Pediatric contractures in burn injury: a burn model system national database study. J Burn Care Res. 2017;38:e192-9.
11. Kowalske K, Holavanahalli R, Sergio M, Esselman P, Ware L, Delateur B, et al. Contractures following burn injury in children and adults. J Burn Care Res. 2003;24:S85.
12. Kidd LR, Nguyen DQ, Lyons SC, Dickson WA. Following up the follow up-long-term complications in paediatric burns. Burns. 2013;39:55-60.
13. Gorga D, Johnson J, Bentley A, Silverberg R, Glassman M, Madden M, et al. The physical, functional, and developmental outcome of pediatric burn survivors from 1 to 12 months postinjury. J Burn Care Rehabil. 1999;20:171-8.
14. Dobbs ER, Curreri PW. Burns analysis of results of physical therapy in 681 patients. J Trauma. 1972;12:242-8.
15. Schneider JC, Holavanahalli R, Helm P, O'Neil C, Goldstein R, Kowalske K. Contractures in burn injury part II: investigating joints of the hand. J Burn Care Res. 2008;29:606-13.
16. Oosterwijk AM, Nieuwenhuis MK, van der Schans CP, Disseldorp LM, Mouton LJ. Why an operationalization of flexibility problem after scars is needed in terms of function (abstract). In: ScarCon ETRS 2018 Joint meeting scar academy and the European Tissue Repair Society: Okura Hotel, Amsterdam, The Netherlands, May 31-June 2, 2018. Wound Repair Regen 201826: A28.
17. Oosterwijk AM, Nieuwenhuis MK, van der Schans CP, Mouton LJ. Shoulder and elbow range of motion for the performance of activities of daily living: a systematic review. Physiother Theory Pract. 2018;29:1-28.
18. Klerks M, Niemeijer A, Jelsma D, Smits-Engelsman B. Defining hyper and hypo

mobility for passive joint motion in children aged 3-16 years [abstract and poster]. Physiotherapy 2011. Heading Professional Practice: Paediatrics: Musculoskeletal [Accessed 7 February 2018] http://www.abstractstosubmit. com/ wpt2011/abstracts/.

19. Korp K, Richard R, Hawkins D. Refining the idiom "functional range of motion" related to burn recovery. J Burn Care Res. 2015;36:e136-45.
20. Akkerman M, Mouton LJ, Niemeijer AS, Van Baar ME, Jelsma N, Van der Woude LHV, et al. Evolution of muscular strength and aerobic capacity after acute pediatric burns. Ann Burns Fire Dis. 2017;30(Suppl. EBA):66-7.
21. Schouten HJ, Nieuwenhuis MK, van Baar ME, van der Schans CP, Niemeijer AS, van Zuijlen PPM. The prevalence and development of burn scar contractures. A prospective multicenter cohort study. Burns. 2018 (final revisions submitted).
22. Goverman J, Mathews K, Goldstein R, Holavanahalli R, Kowalske K, Esselman P, et al. Adult contractures in burn injury: a burn model system national database study. J Burn Care Res. 2017;38:e328-36.
23. Hawkins HK, Jay J, Finnerty CC. Pathophysiology of the burn scar. In: Herndon DN, editor. Total burn care. 5th ed. Edinburgh: Elsevier Inc.; 2018:466-75.
24. van der Wal MBA, Vloemans JFPM, Tuinebreijer WE, van der Ven P, van Unen E, van Zuijlen PPM, et al. Outcome after burns: an observational study on burn scar maturation and predictors for severe scarring. Wound Repair Regen. 2012;20:676-87.
25. Fisher M. Pediatric burn reconstruction: focus on evidence. Clin Plast Surg. 2017;44:865-73.
26. Capek KD, Zapata-Sirvent R, Huang TT. Management of contractural deformities involving the shoulder (axilla), elbow, hip, and knee joints in burned patients. In: Herndon DN, editor. Total burn care. 5th ed. Edinburgh: Elsevier Inc.; 2018:573-88.
27. Godleski M, Oeffling A, Bruflat AK, Craig E, Wietzenkamp D, Lindberg G. Treating burn-associated joint contracture: results of an inpatient rehabilitation stretching protocol. J Burn Care Res. 2013;34:420-6.
28. Perera AD, Perera C, Karunanayake A. Effectiveness of early stretching exercises for range of motion in the shoulder joint and quality of functional recovery in patients with burns - a randomized control trial. Int J Physiother. 2017;4:302-10.
29. Carswell A, McCollM A, Baptiste S, Law M, Polatajko H, Pollock N. The Canadian Occupational Performance Measure: a research and clinical literature review. Can J Occup Ther. 2004;71:210-22.
30. Stratford P, Gill C, Westaway M, Binkley J. Assessing disability and change on individual patients: a report of a patient specific measure. Physiother Can. 1995;47:258-63.
31. Palmieri TL, Petuskey K, Bagley A, Takashiba S, Greenhalgh DG, Rab GT. Alterations in functional movement after axillary burn scar contracture: a motion analysis study. J Burn Care Rehabil. 2003;24:104-8.
32. Mosqueda T, James MA, Petuskey K, Bagley A, Abdala E, Rab G. Kinematic assessment of the upper extremity in brachial plexus birth palsy. J Pediatr Orthop. 2004;24:695-9.
33. Petuskey K, Bagley A, Abdala E, James MA, Rab G. Upper extremity kinematics during functional activities: three-dimensional studies in a normal pediatric population. Gait Posture. 2007;25:573-9.
34. Reid S, Elliott C, Alderson J, Lloyd D, Elliott B. Repeatability of upper limb kinematics for children with and without cerebral palsy. Gait Posture. 2010;32:10-7.

35. Klotz MCM, van Drongelen S, Rettig O, Wenger P, Gantz S, Dreher T, et al. Motion analysis of the upper extremity in children with unilateral cerebral palsy - an assessment of six daily tasks. Res Dev Disabil. 2014;35:2950-7.

36. Livingston LA, Stevenson JM, Olney SJ. Stairclimbing kinematics on stairs of differing dimensions. Arch Phys Med Rehabil. 1991;72:398-402.

7

General discussion

GENERAL DISCUSSION

Main findings of present thesis

This thesis focused on the impact of range of motion (ROM) loss as a result of contracting tissue around or adjacent to joints on daily functioning. To gain insight into the extent of the threat of contractures on the performance of daily tasks, the construct 'contracture' has to be converted into measurable characteristics, i.e., be operationalized. So far, the existence and severity of contractures are expressed in terms of norm ROM, i.e., the maximal ROM of a specific joint in a particular movement direction in unimpaired subjects during active movement. A contracture is than defined as a measured ROM lower than the norm ROM. However, the clinically relevance of this operationalization is questioned. To get insight into the extent of the problem of contractures in terms of function, the main question is 'when is a certain degree of ROM loss actually a problem for the performance of daily tasks?' The central aim addressed in the present thesis is therefore to challenge current operationalizations used to evaluate the presence and severity of contractures and make a start with a new operationalization of the construct 'contracture' in terms of functional outcome in daily life. In this operationalization the term 'functional ROM' is introduced, i.e., the critical joint angles where a certain loss of ROM would hamper a patients natural performance of one or more daily tasks.

The most important issue addressed in this thesis is that the impact of a certain degree of ROM loss on the capacity to naturally perform daily tasks differs per joint and movement direction. This implies that analyzing ROM loss for all joints in the same way, like with the norm ROM-method or its derivatives, is not viable to determine functional outcomes.

Influence of flexibility problems on functioning: where are we now and where do we go from here?

As mentioned in the introduction, in the ICF model the term 'functioning' refers to the dynamic interaction between *body functions and structures, activities* and *participation*, in which a person's health conditions, environmental factors, and personal factors play an important role.[1] The present thesis focused mainly on the role of ROM loss on limitations in daily activities, but over the last decades, progress is being made concerning the influence of flexibility problems on functioning in all components of the ICF model (Figure 1).

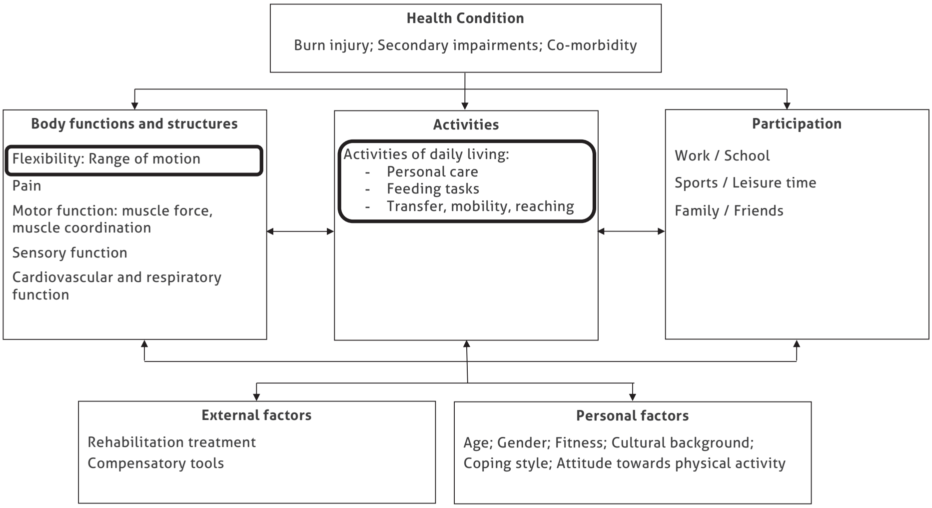

Figure 1 - The dynamic interaction between all components of the ICF model reflecting the influence of flexibility problems on functioning.

Body functions and structures: range of motion

In the present thesis, the only 'body function and structure' that is considered is range of motion. Factors like pain and muscle force are not taken into account, but are also important influencers of functioning. Focusing on ROM, a reliable and valid measurement of joint angles is essential. Furthermore, to gain viable information regarding functional outcomes, the assessment of joint angles has to be in line with the functional positions of joints in which activities are performed. Additionally, knowledge about the time of measurement is crucial.

7

Measuring joint angles during actual performance

Nowadays, clinicians often gain information regarding the amount of ROM loss by global estimations or with the use of a lateral hand-hold goniometer following the standard goniometry protocol of for example Norkin and White.[2-5] However, for reliable measurements in line with function there are some recommendations for clinical practice as well as for research.

For clinical practice it is recommended to measure ROM of a specific joint and movement direction actively instead of passively as this is more in line with the actual performance in daily functioning. Furthermore, as simulated tasks do not replicate the movements required to perform activities of daily living (ADL),[6] the use of functional tasks is preferred to assess functional joint angle requirements even if the functional task require loaded conditions. This latter is likely to occur in tasks where extreme ROMs of the lower extremity joints are needed, e.g., ankle dorsal flexion during stair decent (discussed in chapter 6). When using the hand-hold goniometer, especially in patients with burns, measuring joint angles in functional positions is proposed by using the revised goniometry protocol of Parry et al.[7] instead of the standard protocol. This revised protocol takes into account cutaneous functional units which are skin areas that functionally contribute to ROM of a specific joint. Some of these cutaneous functional units are far beyond the immediate proximity of the joint itself.[8] It is found that more scarring in the associated cutaneous functional unit correlated with less maximal motion.[9]

Although measuring joint angles with a hand-hold goniometer using the revised goniometry protocol is a step forward, the reliability of the goniometer is inconclusive and the minimal detectable difference is high, at least in patients with burns.[4,10-11] Moreover, analyzing multiple connecting joints that are involved in an activity is crucial due to the cutaneokinematic complexity and interconnectivity between joints,[8,12] but unfeasible with this device. For the accurate determination of multiple joint angles during actual performance, the use of optical 3D systems is possible and required, especially in the field of research. The known problems are that these 3D systems are expensive, not portable and joint angle analysis is complicated. Furthermore, joint angles are not detectable during dressing tasks so far as clothes cover the markers of the camera motion capture system. Further research should therefore focus on a 3D measurement system that is easy to use in research, and if possible also in the clinical settings, by overcoming these present issues as well as the problem of 'gimbal lock'.

Time of measurement

Another issue is the time of measurement of joint angles. Measuring at an early stage after diagnosis of a disease or injury is very valuable if, for example in burns, knowledge about the scar maturation process is available. Concerning burn injury, a lot of studies measure joint angles at discharge,[13-17] however, these measurements seems to have little predictive value on the long-term.[18] Between wound closure and the end of scar maturation, the ROM of a certain joint that has burns across or adjacent to it fluctuates. Up to six months after wound closure, it is known that scar contracting increases gradually, which is supported by the finding that in this period the pliability of the scar decreases and thickness increases.[19,20] To predict functional problems in the performance of daily tasks on the long-term, the end point of measuring ROM has to be the end of scar maturation, however, it is unclear when exactly this is after wound closure. To gain more insight into the scar maturation process over time, longitudinal studies are needed that analyze joint angles and functional problems of scar contractures from wound closure till at least a period of twelve months after wound closure and preferably beyond. In children, a longer period of time is desirable as fluctuations in ROM can also be variable due to the fact that increment of scar contractures can be expected when their growth exceed the capacity of scars to grow.[21]

Activities: functional ROM

In the present thesis, the term 'functional ROM' is introduced. This functional ROM is defined as the ROM that is needed to perform daily tasks naturally without compensatory movements. A contracture that limits the performance of daily tasks is than defined as a measured ROM below this functional ROM per joint and movement direction separately. Data of functional ROM are derived from the literature and come from our findings (chapter 3) and those of Korp et al.[12] This functional ROM-method is the first step in the operationalization of the construct 'contracture' in terms of function outcomes in daily life. If this method get broad worldwide support, the functional ROM has to be optimized on several points.

In chapter 3, 'activities of daily living' is divided into two subcategories: 'personal care and feeding' and 'other daily, leisure and work tasks'. In the literature more or less comparable subcategories 'basic ADL' and 'instrumental ADL' are used.[22,23] Being able to perform basic daily activities is crucial for independent living as it consist of self-care tasks and is generic for all people. Knowledge about the functional ROMs for basic ADL tasks is therefore extremely relevant and should, for this reason, receive special attention in research and also be a primary therapeutic aim in clinical practice. Whether also the functional ROM of all instrumental ADL tasks needs to be analyzed, is open for discussion, as these tasks are more variable per person and variable over time.

Moreover, although a large set of ADL tasks were measured resulting in the present functional ROMs, this set is not complete yet as ADL tasks like dressing or driving were not systematically studied. If joint angle data of healthy subjects performing a large set of ADL tasks becomes available, the current functional ROM may change for some joints and movement directions.

Finally, functional ROMs need to be determined in all extremity joints of healthy subjects and preferably these subjects cover a wide range of different characteristics like age, gender and hand dominance, as postural and performance variability can influence the needed joint angles.[24-27]

Participation: individual functional problems

Participation restrictions are defined as problems that an individual may experience in involvement in life situations.[1] Although participation was not the focus of the present thesis, it is highly relevant for the individual. Therefore, knowledge about perceived impact on participation by the patient is essential. This information should be used for shared decision making between the patient and clinician, resulting in a tailored made rehabilitation program. Despite asking or observing the patient for their participation restrictions, patient-report outcome measures can be used like the Canadian Occupational Performance Measure (COPM)[28] or Patient Specific Functional Scale (PSFS).[29] However, as mentioned in the introduction, when perceived participation restrictions are scored by such questionnaires, it is difficult to identify the influence of single factors like ROM loss, pain, loss of muscle force, loss of muscle coordination, loss of sensibility or even personal/environmental factors. Furthermore, the use of compensatory movements during participation is neglected which can influence the outcome on the questionnaire. In line with Korp et al., [12] future studies should include correlations between ROM measurements and patient-report outcome measures.

Personal, external and disease or injury related factors

Personal and external factors can serve as risk factors for the development of contractures that limit functioning. Per disease or injury, also other risk factors can influence this development and therefore the functional outcome. The personal factors consist of several subject characteristics like age, gender, race, fitness, cultural background, coping style, attitude towards physical activity and hand dominance. External factors are for example rehabilitation treatment options, costs of treatments, distance from home to the hospital and available compensatory tools to compensate for significant limitations in functioning. Specific burn characteristics can include percentage total body surface area (%TBSA) burned, percentage full thickness burns, etiology of the burn, location of the burn and the influence of multiple connecting burned joints.

Till now, risk factors for the development of scar contractures after burns are a larger percentage TBSA burned, a larger percentage full thickness burns, being a child, women, having flame burns, burns at the cervical spine and the upper extremity (chapter 1),[18] however, these risk factors are based on ROM measurements below the norm (norm ROM-method). For the future, substantial cohort studies covering all aspects of the patient group are required to determine the risk factors for contractures that limit daily functioning by using the functional ROM-method. Unfortunately, a small sample size as well as a heterogeneous patient group are common in burn research. A method to challenge these aspects is by collecting multicenter data and assessing ROM during regular visits to the burn center. A larger ROM dataset in combination with data from an (inter)national registration system also offers the opportunity to identify other risk factors.

Predicting functional problems on the long-term

Back to clinical practice, in which the patient is diagnosed with a certain disease or injury. The clinician and patient are in a conversation about the patients future functioning. To advise the patient, the question is: what information does the clinician need concerning contractures that limit functioning on the long term and how should research address this? In other words, how can we optimize tailored health care?

In order to correctly inform patients and relatives, optimize rehabilitation management, assist medical decision-making, set suitable long-term treatment goals, and reduce costs, knowledge about factors that determine final functional outcome of patients is very important.[30] A clinical prediction model should be able to determine the future functional outcome regarding a particular measure for a single patient, based on valid examination of prognostic risk factors that have been found in a representative sample of the study population with the same characteristics. To construct such a prediction model, clarification about future outcomes to predict (endpoints) and baseline health status (starting points) are needed.[30] For functional recovery, the clinically most feasible relevant endpoint is the 'activity' level in the ICF framework, as on 'participation' level the outcomes to predict are too subjective and variable.

Especially for contracture management, the ultimate goal is to adequate predict long-term joint flexibility problems in terms of daily tasks performance based on valid and reliable ROM measurements and several risk factors. Even more specific, the baseline health care status (starting points) consist of ROM measurements in an early stage after diagnosis of a disease or injury in combination with personal and external factors as well as disease or injury related characteristics. The endpoint is whether or not joint angles are a problem for the naturally performance of daily tasks, thus the functional ROM (Figure 2).

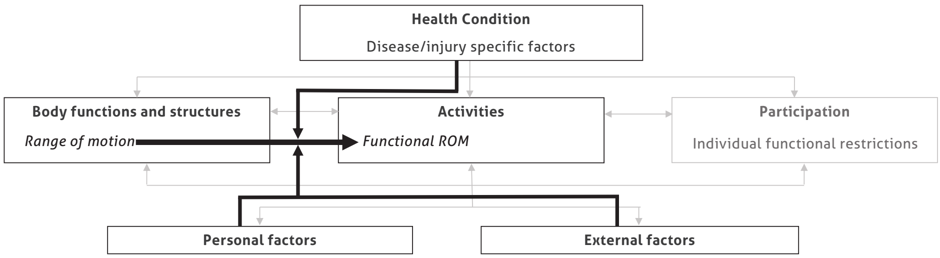

Figure 2 - Prediction model to prognosticate if functional ROM can be reached on the long-term.

When such a prediction model becomes available for the clinician to predict functional problems in daily life on the long term at an early stage after the diagnosis of disease or injury, this knowledge can be used for shared decision making and tailored treatment. The first outcome option of such a prediction model is that functional ROM will be reached with the natural recovery progress without further treatment. The second option is that functional ROM will not be reached with the natural recovery progress, but the problem can be overcome by treatments. The third option is that, despite treatment efforts, functional ROM for the performance of daily activities will not be reached. Then, activities of daily living could be accomplished by compensatory movements of other components of the coordinated joint system. However, such movements pose a risk for overuse problems on the long-term, like soft tissue problems and earlier degenerative symptoms in the joint.[31-33] Till now, information about the magnitude of this risk, depending on how often, for how long, and at which angle these compensatory movements are necessary during the day, is lacking and needs future research in order to make decisions in the rehabilitation process. The final outcome option of the prediction model is that the contracture will seriously threaten the performance of daily tasks so that even compensatory movements are inadequate. Then changes in the environment, compensatory tools, or help from others is necessary for daily functioning.

So far this prediction focused on reaching functional ROM on the long term with or without treatment or compensation. If in the future adequate predictions can be made on 'activity' level, the conversation between clinician and patient will move to 'participation' level, i.e., what prospective functional restrictions can the patient expect in involvement in life situations. Then again, shared decision making is important for a tailored treatment plan.

CONCLUSION

Ultimately, the significance of loss of joint flexibility lies in its limitation of function. The functional ROM-method is recommended to operationalize the construct 'contracture' into measurable characteristics in terms of daily functioning. Moving forward, an international effort should be made to further develop the protocol to do so.

REFERENCES

1. World Health Organization. International Classification of Functioning, Disability and Health (ICF). 2001.
2. Lea RD, Gerhardt JJ. Range-of-motion measurements. J Bone Joint Surg Am. 1995;77:784-98.
3. Norkin CC, White DJ. Measurement of joint motion: a guide to goniometry. 4th ed. Portland: FA Davis Company; 2009.
4. Edgar D, Finlay V, Wu A, Wood F. Goniometry and linear assessments to monitor movement outcomes: are they reliable tools in burn survivors? Burns 2009;35:58-62.
5. Parry I, Walker K, Niszczak J, Palmieri T, Greenhalgh D. Methods and tools used for the measurement of burn scar contracture. J Burn Care Res 2010;31:888-903.
6. Taylor SAF, Kedgley AE, Humphries A, Shaheen AF. Simulated activities of daily living do not replicate functional upper limb movement or reduce movement variability. J Biomech 2018;76:119-28.
7. Parry I, Richard R, Aden JK, Yelvington M, Ware L, Dewey W, Jacobson K, Caffrey J, Sen S. Goniometric measurement of burn scar contracture: a paradigm shift challenging the standard. J Burn Care Res 2019;40:377-85.
8. Richard RL, Lester ME, Miller SF, Bailey JK, Hedman TL, Dewey WS, Greer M, Renz EM, Wolf SE, Blackbourne LH. Identification of cutaneous functional units related to burn scar contracture development. J Burn Care Res 2009;30:625-31.
9. Parry I, Sen S, Sattler-Petrocchi K, Greenhalgh D, Palmieri T. Cutaneous functional units predict shoulder range of motion recovery in children receiving rehabilitation. J Burn Care Res. 2017;38:106-11.
10. van Trijffel E, van de Pol RJ, Oostendorp RA, Lucas C. Inter-rater reliability for measurement of passive physiological movements in lower extremity joints is generally low: a systematic review. J Physiother 2010;56:223-35.
11. van de Pol RJ, van Trijffel E, Lucas C. Inter-rater reliability for measurement of passive physiological range of motion of upper extremity joints is better if instruments are used: a systematic review. J Physiother 2010;56:7-17.
12. Korp K, Richard R, Hawkins D. Refining the idiom "functional range of motion" related to burn recovery. J Burn Care Res 2015; 36:e136-45.
13. Schneider JC, Holavanahalli R, Helm P, Goldstein R, Kowalske K. Contractures in burn injury: defining the problem. J Burn Care Res 2006;27:508-14.
14. Goverman J, Mathews K, Goldstein R, Holavanahalli R, Kowalske K, Esselman P, et al. Pediatric contractures in burn injury: a burn model system national database study. J Burn Care Res 2017;38:e192-9.
15. Kowalske K, Holavanahalli, R, Sergio M, Esselman P, Ware L, Delateur B, et al. Contractures following burn injury in children and adults. J Burn Care Res 2003;24:S85.
16. Schneider JC, Holavanahalli R, Helm P, O'Neil C, Goldstein R, Kowalske K. Contractures in burn injury part II: investigating joints of the hand. J Burn Care Res 2008;29:606-13.
17. Goverman J, Mathews K, Goldstein R, Holavanahalli R, Kowalske K, Esselman P, et al. Adult contractures in burn injury: a burn model system national database study. J Burn Care Res 2017;38:e328-36.
18. Schouten HJ, Nieuwenhuis MK, van Baar ME, van der Schans CP, Niemeijer AS, van Zuijlen PPM. The prevalence and development of burn scar contractures: a prospective multicenter cohort study. Burns 2019;45:783-90.

19. Hawkins HK, Jay J, Finnerty CC. Pathophysiology of the burn scar. In: Herndon DN, editor. Total Burn Care. 5th ed. Edinburgh: Elsevier Inc; 2018, p.466-75.
20. van der Wal MBA, Vloemans JFPM, Tuinebreijer WE, van der Ven P, van Unen E, van Zuijlen PPM, et al. Outcome after burns: an observational study on burn scar maturation and predictors for severe scarring. Wound Repair Regen 2012;20:676-87.
21. Fisher M. Pediatric burn reconstruction: focus on evidence. Clin Plast Surg 2017;44:865-73.
22. Katz S, Ford AB, Moskowitz RW, Jackson BA, Jaffe MW. Studies of illness in the aged. The index of ADL: a standardized measure of biological and psychosocial function. JAMA. 1963;185:914-9.
23. Lawton MP, Brody EM. Assessment of older people: self-maintaining and instrumental activities of daily living. Gerontologist. 1969; 9:179-86.
24. Barnes CJ, Van Steyn SJ, Fischer RA. The effects of age, sex, and shoulder dominance on range of motion of the shoulder. Journal of Shoulder and Elbow Surgery 2001;10:242-6.
25. Doriot N, Wang X .Effects of age and gender on maximum voluntary range of motion of the upper body joints. Ergonomics 2006;49:269-81.
26. Chateauroux E, Wang X. Effects of age, gender, and target location on seated reach capacity and posture. Hum Factors 2008;50:211-26.
27. Stathokostas L, McDonald MW, Little RM, Paterson DH. Flexibility of older adults aged 55-86 years and the influence of physical activity. Journal of Aging Research 2013:743843.
28. Carswell A, McColl MA, Baptiste S, Law M, Polatajko H, Pollock N. The Canadian Occupational Performance Measure: a research and clinical literature review. Can J Occup Ther 2004;71:210-22.
29. Stratford P, Gill C, Westaway M, Binkley J. Assessing disability and change on individual patients: a report of a patient specific measure. Physiother Can 1995;47:258-63.
30. Lee Y, Bang H, Kim DJ. How to establish clinical predition models. Endocrinol Metab (Seoul) 2016;31:38-44.
31. Mell AG, Childress BL, Hughes RE. The effect of wearing a wrist splint on shoulder kinematics during object manipulation. Archives of Physical Medicine and Rehabilitation 2005;86:1661-4.
32. Veeger HE, Magermans DJ, Nagels J, Chadwick EK, van der Helm FC. A kinematical analysis of the shoulder after arthroplasty during a hair combing task. Clinical Biomechanics 2006;21(Suppl 1):S39-44.
33. de Groot JH, Angulo SM, Meskers CG, van der Heijden-Maessen HC, Arendzen JH. Reduced elbow mobility affects the flexion or extension domain in activities of daily living. Clinical Biomechanics 2011;26:713-7.

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Appendices

Summary in English
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SUMMARY IN ENGLISH

To perform activities, a sufficient range of motion (ROM) in each specific movement direction of all joints is required. Unfortunately, loss of ROM is a well-known complication of various clinical conditions, amongst which burn injuries. After burns, shortening of skin tissue can result in loss of ROM, which is called a scar contracture. Scar contractures can threaten functioning, including the performance of daily tasks, participation and health-related quality of life. For this reason, treatments and rehabilitation programs after burns have a strong focus on minimizing scars and scar contractures. To enable evaluations of these treatments and care, insight in the prevalence, course and severity of scar contractures is essential. Till now, a contracture is defined as a measured ROM lower than the corresponding norm ROM, i.e., the maximal ROM of a specific joint in a particular movement direction in unimpaired subjects during active movement. However, this description does not take functioning into account. To consider contractures in terms of functioning the main issue is: when is a certain degree of ROM loss actually a problem for the performance of daily tasks? In the present thesis current methods used to evaluate the presence and severity of scar contractures are challenged and a start is made with the operationalization of the construct 'contracture' in terms of functional outcomes in daily life. To accomplish this, the term 'functional ROM' is introduced, i.e., the critical point where a certain loss of ROM would hamper a patient's natural performance of one or more daily tasks.

Main findings

To evaluate current care and direct new treatment strategies to prevent and/or correct burn scar contractures, insight into its prevalence and risk factors is essential. Therefore, in **CHAPTER 2** the literature concerning the prevalence and risk factors of scar contractures over the last decades was systematically reviewed. Data were extracted regarding study, subject and burn characteristics, method of scar assessment, point prevalence and possible determinants. Nine studies and one abstract provided the number of patients admitted to a burn center in a specified inclusion period as well as the number of patients with scar contractures from this population at a certain moment after burn injury. These studies covered very heterogeneous patient groups and were in general of poor methodological quality. The primary conclusion of this systematic review was that information concerning the prevalence of scar contractures is scarce and, moreover, prevalence values varied considerably between studies. The prevalence at discharge was 38% - 54%, but with a longer time after burn injury, the prevalence was lower. Furthermore, scar contractures were more likely to occur in more severe burns, children, women, after flame burns, at the cervical spine and the upper extremity. Remarkably, over almost four decades there appeared to be no obvi-

ous decrease in prevalence during recovery. This systematic review also highlighted that, if reported, studies used the norm-based method to define 'contracture', i.e., a measured ROM below the norm ROM. Some authors of the included studies, however, noted that this method is disputable and a new method is desirable in which the severity of a contracture is classified based on functional outcomes.

As a loss of ROM can interfere with the performance of daily tasks, many interventions focus on improving impaired ROM. However, in order to set treatment goals in terms of function, the question is what joint angles are minimally required to naturally perform daily tasks. These required joint angles, subsequently called functional ROMs in this thesis, are defined as the ROMs per joint and movement direction that unimpaired subject use to accomplish daily tasks. The purpose of the second systematic review of this thesis was to determine the functional ROMs for the shoulder and elbow joint (**CHAPTER 3**). Thirty-six studies were included involving a total of 66 daily tasks performed by unimpaired subjects. The risk of bias of these studies was low to moderate. A thorough analysis of results showed that healthy subjects used up to 152° elbow flexion and -1° extension in personal care and feeding tasks. These angles are close to the norm ROMs of 150 and 0°, respectively. However, for shoulder flexion and abduction approximately 130° was necessary for the reported daily tasks, which is far lower than the norm ROM of 180°. These results clearly showed that the impact of ROM loss on the capacity to naturally perform daily tasks differs per joint and movement direction.

To classify the severity of a certain ROM loss, different rating scales exist in the field of orthopedics, physiotherapy as well as burn. Such scales consist of different severity levels ranging from 'severe impairment' to 'no impairment'. However, cut-off points between the different levels of severity vary between scales, and it seems unclear if and how these cut-off points relate to limitations in functioning. To illustrate the effects of differences in classifications, shoulder flexion and elbow flexion passive ROM data of patients three months after burn injury were rated in a total of six existing shoulder rating scales and 12 elbow rating scales in **CHAPTER 4**. Subsequently, outcomes were related to the functional ROMs required for the naturally performance of daily tasks, derived from the above-mentioned review (CHAPTER 3). Results showed large differences in the number of levels of severity per scale. For the shoulder the number of severity levels ranged from three to six, and for the elbow from two to eight. Furthermore, there were large differences in the joint angles corresponding to the used cut-off points. As a consequence, rating the ROM outcomes of burn patients with the different rating scales showed substantial inconsistency in the number of joints with severe impairment and without impairment. The percentage of joints rated as severely impaired ranged from <10% to 29% for the shoulder and from 0% to 17% for the elbow, while the percentage of non-impaired joints ranged from 14% to 36% for the shoulder and from 26% to 100% for the elbow. More importantly, cut-off points of most scales were not related to functional outcomes. As a consequence it was concluded that the use of various classifications obscures the true impact of contractures and hampers clinical practice as well as research.

Dissatisfaction is being voiced with the generally used way in which contractures are defined, i.e., a measured ROM lower than the norm ROM of unimpaired subjects, as the relation with functional outcomes is missing. Alternative operationalizations are available to define the construct 'contracture'. The aim the study in **CHAPTER 5** was to determine the effect of using five different operationalizations by calculating prevalences. For this purpose one single dataset was used. This dataset from a cross-sectional study covered passive ROM data of 95 joints affected by burns of 23 children as well as patient-reported outcomes of 18 functional items of the Burn Outcome Questionnaire (BOQ). The five operationalizations were: measured ROM below norm ROM (method 1), measured ROM below norm ROM minus 1SD (method 2), measured ROM below norm ROM minus 2SD (method 3), measured ROM below functional ROM (method 4), a score of 2 or more on the Likert Scale on any item of the BOQ (method 5). Results showed that the operationalization used to identify contracture substantially influenced the prevalence on group level and per movement direction. Prevalence on group level ranged from 13% to 100%. The comparison of prevalences per joint determined with the different methods showed a difference of ≥40% between the highest and lowest outcome for each movement direction. For almost all movement directions, lower prevalences were indicated according to the functional ROM-method (method 4) in comparison with those of norm-based method (method 1).

Reports regarding the course of scar contractures after burns are scarce and, moreover, not focused on function. In order to evaluate the extent of scar contractures after burns over a longer period of time and taking into account functional outcomes, ROM data originating from a multi-center longitudinal prospective cohort study were used and compared with the functional ROMs derived from CHAPTER 3 for shoulder and elbow, and from Korp et al. (2015) for wrist, knee and ankle (**CHAPTER 6**). The course of prevalence of scar contractures that limit daily functioning over the initial six months after discharge was analyzed in 20 children and adolescents with burns using passive ROM data of 57 joints. This study showed that even six months after discharge over 75% of the children and adolescents with burns had one or more scar contractures limiting daily function. At discharge, less function limiting scar contractures were found for the upper extremity (30%) than for the lower extremity

(53%), while over time, prevalence of scar contractures that limit function fluctuated in both extremities between 22% and 35%. At none of the time points, significant differences between upper and lower extremity joints were found. Moreover, results showed that measuring ROM at discharge has little predictive value in the long-term. Substantial longitudinal studies over a longer period of time are needed to increase knowledge on the course of scar contractures to support improvements in burn care.

Discussion and conclusion

CHAPTER 7 presents the general discussion and conclusion. The main finding of this thesis is that the impact of a certain degree loss of ROM on the capacity to perform daily activities differs per joint and movement direction. This implies that analyzing loss of ROM for all joints in the same way, like the norm ROM-method or its derivatives do, cannot determine the actual impact of ROM loss on functioning. Our research group therefore advocates international consensus on a new function-based operationalization of the construct 'contracture'. Moreover, we argue for further research to clarify the relationship between loss of ROM and functional limitations.

In the discussion varies points of attention are discussed, including measuring active ROM instead of passive ROM; measuring ROM in functional positions instead of the usual anatomical positions, with a goniometer or a 3D system; conducting longitudinal studies that measure joint angles throughout the entire scar maturation process; optimizing the functional ROM-method that includes all daily tasks, in different age groups and in both genders; making correlations between ROM measurements and barriers that patients experience in daily life and participation; determining the influence of various personal factors, environmental factors and burn specific factors that may be a risk factor for the development of scar contractures that limit functioning; and gaining more insight into the extent to which compensatory movements pose a risk for degenerative problems in the longer-term.

The functional ROM-method introduced in this thesis may be used to provide an indication of expected functional limitations on the long-term. Thereafter, this indication can be included in the decision to start specific treatments, whether or not allow adequate compensatory movements, whether or not strive for adjustments in the environment and/or purchase compensatory tools, or enlisting help of others for daily functioning.

It should be noted that the introduced functional ROM-method is aimed at the activity level, while in practice the patient is also involved in life situations on participation level of course, which varies per individual. Therefore, a tailored rehabilitation program always requires a good conversation between the clinician and patient to come to shared decision making.

In conclusion, the significance of determining loss of joint flexibility lies in the limitation of functioning. That is why it is recommended to operationalize the construct 'contracture' in measurable variables related to (daily) functioning.

NEDERLANDSE SAMENVATTING

Om dagelijkse activiteiten uit te kunnen voeren is voldoende flexibiliteit in alle gewrichten met bijbehorende bewegingsrichtingen nodig. Deze flexibiliteit wordt uitgedrukt in de hoeveelheid graden waarover kan worden bewogen in een gewricht, ook wel de range of motion (ROM) genoemd. Helaas is een verminderde flexibiliteit in één of meerdere bewegingsrichtingen van een gewricht een veelvoorkomende complicatie bij verschillende ziektes en aandoeningen, waaronder brandwonden. Een verminderde flexibiliteit kan het functioneren belemmeren, waaronder de uitvoering van dagelijkse taken en participatie in de samenleving. Op grond hiervan kan ook de gezondheid gerelateerde kwaliteit van leven worden aangetast.

Brandwonden en contracturen

Bij het oplopen van brandwonden, treedt schade aan de huid op. Vervolgens treden er tijdens de wondgenezing herstelprocessen op waardoor na de wondsluiting dikke, stugge en nog samentrekkende littekens kunnen ontstaan. Indien zo'n litteken over een gewricht loopt, kan dit leiden tot verlies van flexibiliteit in dit gewricht. Een dergelijk verlies aan flexibiliteit door een samentrekkend litteken wordt een littekencontractuur genoemd. Littekencontracturen komen met name voor bij verbrandingen van volledige dikte, zoals bij een vlamverbranding.

Gezien de mogelijk grote impact van littekencontracturen op het functioneren van een persoon is de behandeling van brandwonden al vele jaren onder andere gericht op het voorkomen en minimaliseren van littekencontracturen. Helaas zijn littekencontracturen na brandwonden nog steeds een aanzienlijk probleem. Het is echter gecompliceerd om inzicht te krijgen in hoe vaak deze littekencontracturen voorkomen, hoe ernstig ze zijn en hoe de ontwikkeling van littekencontracturen in de loop van de tijd is, omdat de operationalisatie van het construct 'contractuur' ter discussie staat. Namelijk, welke methode is optimaal om het construct 'contractuur' om te zetten in meetbare variabelen?

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Probleemstelling: operationalisatie van het construct 'contractuur'

Tot nu toe wordt een contractuur geoperationaliseerd als een gemeten ROM lager dan de bijbehorende norm ROM. Hierbij is de norm ROM gedefinieerd als de maximale ROM in een specifieke bewegingsrichting van een gewricht die gezonde mensen kunnen uitvoeren tijdens actief bewegen. De norm ROM voor schouderabductie is bijvoorbeeld 180 graden, voor elleboogextensie 0 graden en voor knieflexie 135 graden. Echter, met deze keuze van operationalisatie van het construct 'contractuur' wordt geen rekening gehouden met functioneren in het dagelijks leven. Stel dat er een verlies is van een paar graden ROM, dan is dit volgens deze operationalisatie een contractuur, maar dit hoeft niet te betekenen dat het dagelijks functioneren wordt belemmerd. Om het construct 'contractuur' te operationaliseren in (meetbare) termen die het dagelijks functioneren reflecteren, is de centrale vraag: wanneer is het verlies van een bepaald aantal graden ROM daadwerkelijk een probleem voor de uitvoering van dagelijkse taken? Bijvoorbeeld, wanneer kan iemand zijn of haar haren niet meer op een natuurlijke manier kammen zonder te hoeven compenseren?

In dit proefschrift wordt er een nieuwe, functionele operationalisatie van het construct 'contractuur' voorgesteld. Om tot deze functionele benadering te komen, is de term 'functionele ROM' geïntroduceerd. Deze functionele ROM is per gewricht en bewegingsrichting de ROM die gezonde mensen gebruiken voor een natuurlijke uitvoering van dagelijkse activiteiten. Indien een gemeten ROM lager is dan de functionele ROM, kan dit leiden tot problemen met de natuurlijke uitvoering van een of meerdere dagelijkse taken. Dit resulteert in een contractuur die daadwerkelijk een impact heeft op het dagelijks functioneren. Het centrale doel van het huidige proefschrift is om bestaande kennis over de prevalentie en ernst van littekencontracturen bij mensen met brandwonden bijeen te brengen en te bediscussiëren in het licht van zowel bestaande niet-functie-gerelateerde operationalisaties van het construct 'contractuur' als de nieuwe voorgestelde functionele operationalisatie.

Belangrijkste bevindingen

Om de huidige kennis over de omvang van littekencontracturen te vergroten is het allereerst belangrijk om te weten te komen wat hierover al bekend is. In **HOOFDSTUK 2** werd daarom de literatuur systematisch bestudeerd, waarbij de prevalentie van littekencontracturen na brandwonden in kaart werd gebracht over de afgelopen decennia, evenals mogelijke determinanten. In totaal konden er slechts negen artikelen en één abstract worden geïncludeerd voor verdere analyse. De beschreven prevalentie bij ontslag uit het ziekenhuis varieerde van 38% tot 54%. In een aantal onderzoeken is deze prevalentie ook bepaald op latere meetmomenten, variërend van een maand tot meerdere jaren na het brandwondenongeval. Op deze latere meetmomenten was de prevalentie lager, namelijk 2% tot 32%. Opvallend hierbij was dat er in de periode tussen 1972 en 2013 waarin de onderzoeken plaatvonden geen duidelijke vermindering van prevalentie van littekencontracturen werd gevonden. Dit review toonde verder aan dat uitgebreidere en diepere brandwonden, vlamverbranding, het hebben van een jongere leeftijd en het vrouwelijk geslacht risicofactoren voor het ontwikkelen van littekencontracturen zijn, alsook dat littekencontracturen het vaakst de flexibiliteit in de cervicale wervelkolom en de gewrichten van de bovenste extremiteit beperken. Hoewel deze resultaten een eerste indruk gaven over de omvang van littekencontracturen na brandwonden, werden zij verkregen uit een klein aantal studies, met heterogene patiëntgroepen en van lage methodologische kwaliteit. Bovendien werd er in dit review een grote kanttekening geplaatst bij het feit dat een littekencontractuur werd geoperationaliseerd als een gemeten ROM lager dan de norm ROM van het gewricht. Hoewel dit door een aantal van de auteurs van de studies ook als aandachtspunt werd benoemd, kozen zij toch voor deze operationalisatie omdat er geen operationalisatie van het construct 'contractuur' bekend was die de koppeling maakte tussen een beperkte gewrichtsflexibiliteit en functionele uitkomstmaten.

Om behandeldoelen te stellen op basis van functionele uitkomstmaten is het noodzakelijk om kennis te vergaren over de ROM die nodig is om activiteiten van het dagelijks leven uit te kunnen voeren. In **HOOFDSTUK 3** werd daarom een systematische review uitgevoerd met als doel het bepalen van de ROM die gezonde mensen gebruiken tijdens het uitvoeren van activiteiten van het dagelijks leven (ADL). Omdat uit hoofdstuk 2 naar voren kwam dat er zich in de bovenste extremiteit vaak littekencontracturen ontwikkelen na brandwonden, werd besloten om de in ADL gebruikte ROM in eerste instantie voor de schouder en elleboog in kaart te brengen. Er konden 36 studies worden geïncludeerd van veelal een redelijk goede methodologische kwaliteit waarbij in totaal 66 ADL taken werden geanalyseerd. Gezonde mensen gebruikten voor veel ADL taken, waaronder veel taken voor persoonlijke hygiëne en eten/drinken, een elleboogflexie tussen 130° en 152°, hetgeen dicht bij de norm ROM voor deze bewegingsrichting ligt. Een vrijwel volledige elleboogextensie (20° tot 1°) werd gebruikt tijdens het reiken naar objecten en het aantrekken van schoenen. Tijdens de uitvoering van ADL taken werd tot 142° schouderflexie en tot 127° schouderabductie gebruikt. Opvallend hieraan is dat volledige schouderflexie en -abductie dus niet noodzakelijk zijn voor de uitvoering van de geanalyseerde ADL taken. De impact van het verlies van een bepaald aantal graden ROM op de mogelijkheid om dagelijkse taken uit te voeren verschilt dus per gewricht en per bewegingsrichting.

Binnen de orthopedie, fysiotherapie en brandwondenzorg bestaan verschillende schalen om de ernst van een verlies aan gewrichtsflexibiliteit te bepalen. Deze schalen bestaan uit verschillende categorieën, variërend van 'ernstig beperkt' tot 'niet beperkt'. Echter, de grenzen tussen de verschillende categorieën verschillen per schaal en het was onduidelijk of deze grenzen al dan niet een relatie hadden met een beperking in het dagelijks functioneren. In **HOOFDSTUK 4** werden schalen onderling met elkaar vergeleken op categorieën en grenzen. Daarnaast werd het effect van het gebruik van deze verschillende schalen geïllustreerd door prevalenties op grond van deze schalen met elkaar te vergelijken. Deze prevalenties werden vervolgens ook vergeleken met de prevalenties na toepassing van de functionele operationalisatie van het construct 'contractuur'. Voor deze illustratie werden passieve ROM data van schouderflexie en elleboogflexie van 39 patiënten met brandwonden gebruikt. Deze ROM was gemeten op ongeveer drie maanden na het ongeval en werd gescoord op zes schouderschalen en 12 elleboogschalen. De uitkomsten werden vervolgens vergeleken met de functionele ROM waarden zoals beschreven in hoofdstuk 3. Er werden grote verschillen gevonden in het aantal categorieën per schaal. Voor de schouder varieerde het aantal categorieën tussen de drie en zes en voor de elleboog tussen de twee en acht. Daarnaast werden grote verschillen gevonden in de gewrichtshoeken corresponderend met de grenzen van de categorieën. Het scoren van de ROM data van de patiënten met brandwonden in de verschillende schalen resulteerde als gevolg hiervan in grote verschillen in het aantal gewrichten dat geclassificeerd zou worden als 'ernstige beperkt' en 'niet beperkt'. Het percentage schoudergewrichten dat werd bestempeld als 'ernstig beperkt' en als 'niet beperkt' varieerde respectievelijk van <10% tot 29% en van 14% tot 36%. Het percentage elleboogggewrichten dat werd bestempeld als 'ernstig beperkt' en als 'niet beperkt' varieerde respectievelijk van 0% tot 17% en van 26% tot 100%. Het meest opvallend echter was de bevinding dat de grenzen van de categorieën van de meeste schalen geen relatie vertoonden met de functionele ROM die wordt gebruikt in het dagelijks leven. Het gebruik van verschillende schalen reflecteert dus niet de daadwerkelijke functionele impact van contracturen.

Uit bovenstaande onderzoeken blijkt dat een nieuwe operationalisatie van het construct 'contractuur' dus wenselijk is. In **HOOFDSTUK 5** was het doel om de consequenties van het gebruik van vijf verschillende operationalisaties bloot te leggen door de prevalentie van littekencontracturen bij mensen met brandwonden op verschillende manieren te berekenen. Hiervoor werd gebruik gemaakt van één dataset van een cross-sectionele studie waarbij de passieve ROM van 95 gewrichten met een brandwond over of bij het gewricht werd gemeten. Dit betrof 23 kinderen en de metingen vonden een tot vijf jaar na het ongeval plaats. De prevalentie van littekencontracturen werd berekend door de gemeten ROM te vergelijken met: de norm ROM (methode 1), de norm ROM minus 1SD (methode 2), de norm ROM minus 2SD (methode 3) en functionele ROM (methode 4). Tot slot werd er aan de hand van 18 items van de Burn Outcome Questionnaire bepaald of de kinderen met brandwonden ook daadwerkelijk een of meerdere problemen ervaarden in de uitvoeren van dagelijkse taken door een score van 2 of meer op de Likert Schaal in te vullen op één van de items (methode 5). Resultaten lieten zien dat afhankelijk van de operationalisatie die werd toegepast de prevalentiegetallen sterk wisselden, zowel op groepsniveau als op gewrichtsniveau. Op groepsniveau varieerde de prevalenties van 13% tot 100%. Op gewrichtsniveau werd een verschil van ≥40% gevonden tussen de hoogste en laagste uitkomst voor elke bewegingsrichting. Voor vrijwel alle bewegingsrichtingen gold dat er een lagere prevalentie werd gevonden met de functionele ROM-methode dan met de norm ROM-methode.

De kennis over het beloop van de prevalentie van littekencontracturen na brandwonden is schaars en bovendien wordt daarbij geen rekening gehouden met de beperking in het functioneren. Om de omvang van littekencontracturen na brandwonden over een langere periode te evalueren waarbij het functionele aspect in acht wordt genomen, werd in **HOOFDSTUK 6** passieve ROM data van een multicenter longitudinale prospectieve cohortstudie vergeleken met de functionele ROMs uit hoofdstuk 3 voor de schouder en elleboog en met de functionele ROMs van Korp et al. (2015) voor pols, knie en enkel. Het beloop van de prevalentie van littekencontracturen die volgens deze methode het dagelijks functioneren beperken werd geanalyseerd in 20 kinderen en adolescenten met brandwonden op of nabij 57 gewrichten. De meetmomenten waren bij ontslag uit het ziekenhuis en rond de zes weken, drie maanden en zes maanden na ontslag uit het ziekenhuis. Uit de resultaten bleek dat bij ontslag uit het ziekenhuis 89.5% van de kinderen en adolescenten met brandwonden een gemeten ROM waarde hadden in één of meerdere gewrichten die lager was dan de corresponderende functionele ROM die gezonde mensen gebruiken om dagelijkse taken uit te voeren. Deze prevalentie was zes maanden laten nog steeds erg hoog (>75%). Bij ontslag uit het ziekenhuis was de prevalentie van gewrichten met een gemeten ROM waarde lager dan de functionele ROM hoger in de onderste extremiteit (53%) dan in de bovenste extremiteit (30%). Op de latere meetmomenten fluctueerden de prevalenties van bovenste en onderste extremiteit beiden tussen de 22% en 35%, voornamelijk veroorzaakt door beperkingen van elleboogflexie, knieflexie en enkel dorsaal flexie. Op geen van de meetmomenten werd er een significant verschil gevonden in de prevalentie tussen de bovenste en onderste extremiteit. Deze resultaten toonden aan dat het meten van ROM bij ontslag uit het ziekenhuis weinig voorspellende waarde had op de langere termijn.

Discussie en conclusie

In **HOOFDSTUK 7** zijn de algemene discussie en conclusie weergegeven. De belangrijkste bevinding van deze thesis is dat de impact van een bepaald aantal graden verlies van ROM op de capaciteit om dagelijkse activiteiten op natuurlijke wijze uit te voeren verschilt per gewricht en bewegingsrichting. Dit impliceert dat het analyseren van verlies van ROM voor alle gewrichten op dezelfde manier, zoals de norm ROM-methode of afgeleiden hiervan, niet de daadwerkelijke impact van het verlies van ROM op het functioneren kan bepalen. Onze onderzoeksgroep pleit dan ook voor internationale consensus over een nieuwe, functie-gerelateerde operationalisatie van het construct 'contractuur'. De relatie tussen verlies van ROM en beperkingen in het functioneren zal in de toekomst verder moeten worden onderzocht.

In de discussie zijn verder diverse aandachtspunten besproken, waaronder het meten van actieve ROM in plaats van passieve ROM; het meten van ROM in functionele posities in plaats van anatomische posities zoals tot nu toe gebruikelijk, met een goniometer of een 3D systeem; het uitvoeren van longitudinale studies die gewrichtshoeken meten tijdens het gehele ontwikkelingsproces van het litteken; het optimaliseren van de functionele ROM-methode waarbij alle dagelijkse taken worden gemeten, in verschillende leeftijdsgroepen en in beide geslachten; het leggen van correlaties tussen ROM metingen en belemmeringen die patiënten ervaren in het dagelijks leven en participatie; het bepalen van de invloed van verschillende persoonlijke factoren, omgevingsfactoren en specifieke brandwondfactoren die een risicofactor kunnen zijn voor de ontwikkeling van littekencontracturen die het functioneren belemmeren; en meer inzicht krijgen in hoeverre compensatiebewegingen op de langere termijn een risico vormen voor degeneratieve problemen.

De functionele ROM-methode die in deze thesis is geïntroduceerd kan mogelijk gebruikt worden om een indicatie te geven van de te verwachten functionele beperking op de langere termijn. Deze indicatie kan vervolgens worden meegenomen in de beslissing voor het starten van bepaalde behandelingen, het al dan niet toelaten van adequate compensatie bewegingen, het al dan niet streven naar aanpassingen in de omgeving en/of het aanschaffen van hulpmiddelen of het inschakelen van hulp van anderen in het dagelijks functioneren.

Als kanttekening moet worden geplaatst dat de geïntroduceerde functionele ROM-methode gericht is op het activiteitenniveau, daar waar in de praktijk de patiënt natuurlijk ook wil acteren op participatieniveau. Voor een individueel aangepast revalidatieprogramma blijft dus altijd een goed gesprek tussen arts en patiënt nodig om samen tot besluiten te komen.

Concluderend ligt het belang van het bepalen van verlies van gewrichtsflexibiliteit in het vaststellen van de beperking in het functioneren. Daarom wordt sterk aangeraden om het construct 'contractuur' te operationaliseren in meetbare variabelen gerelateerd aan het (dagelijks) functioneren.

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Noor, ik weet nog dat jij een presentatie gaf in mijn eerste jaar van de master Bewegingswetenschappen als introductie voor het schrijven van een review. Eigenlijk was het onderwerp 'range of motion beperkingen door littekencontracturen bij mensen met brandwonden' het enige onderwerp dat ik echt interessant vond. Vanaf dat moment begon jouw begeleiding met betrekking tot het doen van onderzoek. Na het afronden van mijn master was jij degene die met het plan kwam om eens bij Cees aan te kloppen voor een promotietraject. En zo geschiedde. Je werkt zeer systematisch en bekijkt het manuscript nogmaals met een frisse blik vanuit de lezer. Ik heb veel geleerd van jouw kritische manier van denken, het aanbrengen van structuur, het overzichtelijk presenteren, duidelijke afspraken maken en jouw gedrevenheid. Daarvoor wil ik je heel erg bedanken. Af en toe schoof ik eens aan voor een kopje thee en praatten we over persoonlijke omstandigheden. Nog vaker skypeten we, niet zelden 's avonds of in het weekend, om vervolgens in de dagen daarna onze gemaakte afspraken na te komen. Die flexibiliteit en doelgerichtheid paste goed bij mijn manier van werken. Ik hoop dat je in de toekomst nog vele (PhD)studenten zal begeleiden als docent bij Bewegingswetenschappen en als (co)promotor van onderzoeken, want het delen van jouw kennis, vaardigheden en ervaringen is zeer zinvol.

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Het promotietraject deed ik, zoals al genoemd, parttime. In de laatste periode liep mijn promotie parallel aan mijn werkzaamheden als fysiotherapeut bij het Centrum voor Fysiotherapie Beatrixpark in Ede. Ik wil graag alle collega's uit Ede bedanken voor jullie belangstelling en support, maar zeker ook voor jullie flexibiliteit (ja, ja, daar heb je dat woord 'flexibiliteit' weer) die het mij mogelijk maakte om beide werkzaamheden naast elkaar te doen. Ik hoop dat deze mooie fysiotherapiepraktijk nog vele jaren zal innoveren, samenwerken en ontwikkelen.

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Graag wil ik natuurlijk ook mijn familie en schoonfamilie bedanken voor jullie steun, belangstelling, maar ook de ontspanning. Er wordt onwijs veel gelachen, gekletst, spelletjes gespeeld en gesport samen. Er zijn altijd snel handjes paraat als er hulp nodig is. Ook in moeilijkere tijden zijn we er voor elkaar en dat voelt goed. Ik ben er trots op dat ik zo'n (schoon)familie om mij heen heb.

De laatste woorden zijn uiteraard voor mijn naaste familie. René, Mary, Milou, Jaap en Jolien, bedankt, bedankt, bedankt! Lieve papa en mama, jullie hebben ontzettend veel voor mij betekend en doen dat nog steeds. Dat is eigenlijk niet uit te leggen in een paar regels. Jullie staan altijd voor mij klaar in voor- en tegenspoed, bij grote of kleine beslissingen. Bedankt voor de fijne jeugd, liefde, aandacht en support die ik krijg. Milou en Jolien, eigenlijk was ik altijd wel 'druk'. Er waren momenten bij dat het allemaal even teveel was. Jullie merkten dat als een van de eersten, maar samen zijn we sterk. Ik vind het echt een enorme eer om jullie naast mij te hebben staan als paranimfen op mijn promotie. We hebben al zoveel samen meegemaakt, het is heel bijzonder om ook dit samen te doen.

Lieve Cas, ook mijn dank aan jou kan ik niet in een paar regels beschrijven. We zijn nu al ruim 12,5 jaar gelukkig samen. Je hebt het hele traject meegemaakt en aan mijn zijde gestaan. Van mijn keuzestress na het VWO: wordt het fysiotherapie of toch bewegingswetenschappen (uiteindelijk dus beide), tot op heden. Je steunde me door dik en dun. Ik dank je voor de vele tripjes 's ochtends vroeg naar het station. Je aandacht of juist wat afstand op het juiste moment. De laatste jaren werkte ik veel vanuit huis. Vaak kon ik de problemen waar ik tegenaan liep zelf oplossen, maar je hielp me waar je kon. Je zult soms wel gek zijn geworden van het feit dat ik eigenlijk nooit 'vrij' was. Na vandaag is dit hoofdstuk afgesloten. Ik kijk uit naar de vele hoofdstukken die er nog zullen volgen samen met jou!

Anouk

ABOUT THE AUTHOR

Anouk Oosterwijk was born on the 10th of March 1990 in Deventer, the Netherlands. She grew up in Lettele, a small village near Deventer, where she lived together with her parents and two younger sisters. After completing her pre-university education at the Etty Hillesum Lyceum in Deventer, she moved to Groningen to study Human Movement Sciences at the Faculty of Medical Sciences of the University of Groningen. In 2011, she graduated for her Bachelor's degree and started the Master of Human Movement Sciences. During this Master she acquainted with the subject 'scar contractures in people with burns'. She conducted a systematic review which later turned out to be the precursor of her first international publication (Chapter 2). In one of her research internships she collected data on the physical functioning of children with burns as part of a national project. For her Master's Graduation project, she collected range of motion data of inpatients and outpatients with burns at the burn center Martini Hospital in Groningen. Later, the data from both projects were used for two articles (Chapter 4 and 5). Looking back, the title of her Master's Graduation Project 'Scar contractures after burn injury: a functional approach?' proved to be the predecessor of the title of this dissertation.

Anouk remained interested in the subject and therefore applied to Prof. Cees van der Schans for a PhD-trajectory at the Research Group Healthy Ageing, Allied Health Care and Nursing. Immediately after completing her Master's degree in Human Movement Sciences in 2013, she was able to start with her PhD. At the same time, she assisted in setting up the Hanze Active Ageing Lab. Besides her PhD trajectory she started the education Physical Therapy at the School of Health Care Studies of the Hanze University of Groningen. She very successfully completed her Bachelor's degree in Physical Therapy in 2016, including an Honours Programme, and started working as a physiotherapist at the Centrum voor Fysiotherapie Beatrixpark in Ede. She specialized in neuro-rehabilitation over the last years. In the meantime, she has published several articles and presented them at national and international conferences. Anouk currently lives in Heeten with Cas, nearby Raalte.

Anouk Oosterwijk is geboren op 10 maart 1990 in Deventer. Ze groeide op samen met haar ouders en twee jongere zusjes in Lettele, een klein dorpje in de buurt van Deventer. Na het afronden van haar VWO aan het Etty Hillesum Lyceum in Deventer, verhuisde ze naar Groningen om Bewegingswetenschappen te gaan studeren aan de Faculteit Medische Wetenschappen van de Rijksuniversiteit Groningen. In 2011 rondde ze haar Bachelor af en begon ze aan de Master Human Movement Sciences. Tijdens deze Master maakte ze kennis met het onderwerp 'littekencontracturen bij mensen met brandwonden'. Ze schreef er een review over, wat later de voorloper bleek te zijn van haar eerste internationale publicatie (Hoofdstuk 2). Tijdens één van haar onderzoeksstages, verzamelde zij data met betrekking tot het fysiek functioneren bij kinderen met brandwonden als onderdeel van een nationaal project. Voor haar master afstudeerproject verzamelde ze op het brandwondencentrum van het Martini Ziekenhuis in Groningen range of motion data bij klinische en poliklinische patiënten met brandwonden. Later werd de data van beide projecten gebruikt voor twee artikelen (Hoofdstuk 4 en 5). De titel van haar master afstudeerproject 'Scar contractures after burn injury: a functional approach?' bleek achteraf gezien al de voorloper van de titel dit proefschrift.

Anouk bleef geïnteresseerd in dit onderwerp en solliciteerde daarom bij Prof. dr. Cees van der Schans naar een PhD-traject bij het Lectoraat Healthy Ageing, Allied Health Care and Nursing. Gelijk na het afronden van haar Master Human Movement Sciences in 2013, kon ze beginnen met haar PhD. Tegelijkertijd assisteerde ze bij het inrichten van het Hanze Active Ageing Lab. Naast het PhD traject startte ze met de opleiding Fysiotherapie aan de Academie voor Gezondheidsstudies van de Hanzehogeschool Groningen. In 2016 rondde ze deze opleiding zeer succesvol af, inclusief het Honours Programma, waarna ze als fysiotherapeut begon bij het Centrum voor Fysiotherapie Beatrixpark in Ede. Daarbij specialiseerde ze zich in de neurorevalidatie. Ondertussen publiceerde ze meerdere artikelen en presenteerde deze op binnen- en buitenlandse congressen. Inmiddels woont Anouk samen met haar vriend Cas in Heeten, bij Raalte.

INTERNATIONAL PUBLICATIONS

A.M. Oosterwijk, L.J. Mouton, H.J. Schouten, L.M. Disseldorp, C.P. van der Schans, M.K. Nieuwenhuis. Prevalence of scar contractures after burn: a systematic review. *Burns.* 2017;34:41-49.

A.M Oosterwijk, M.K Nieuwenhuis, C.P van der Schans, L.J Mouton. Shoulder and elbow range of motion for the performance of activities of daily living: a systematic review. *Physiotherapy Theory and Practice.* 2018;34:505-528.

A.M. Oosterwijk, M.K. Nieuwenhuis, H.J. Schouten, C.P. van der Schans, L.J. Mouton. Rating scales for shoulder and elbow range of motion impairment: call for a functional approach. *PLoS One.* 2018;13:e0200710.

A.M. Oosterwijk, L.M. Disseldorp, C.P. van der Schans, L.J. Mouton, M.K. Nieuwenhuis. Joint flexibility problems and the impact of its operationalization. *Burns.* 2019;45:1819-1826.

A.M. Oosterwijk, L.J. Mouton, M. Akkerman, M.M. Stoop, M.E. van Baar, S.M.H.J. Scholten-Jaegers, C.P. van der Schans, M.K. Nieuwenhuis. Course of prevalence of scar contractures limiting function: a preliminary study in children and adolescents after burns. *Burns.* 2019;45:1810-1818.

PRESENTATIONS

Oral presentations

Scar contractures after burn injury: a functional approach? *Master afstudeerproject voor de opleiding Human Movement Sciences Groningen*, 2013 [Groningen, The Netherlands]

Prevalence of burn scar contractures: a systematic review. *15th European Burn Association (EBA) congress*, 2013 [Vienna, Austria]

People with burns: functional recovery of burn scar contractures. *Honours talentprogramma Hanzehogeschool Gezondheidsstudies*, 2015 [Groningen, The Netherlands]

Functional recovery of burn scar contractures. *Studiedag docenten fysiotherapie Hanzehogeschool Groningen*, 2016 [Groningen, The Netherlands]

Rating scales for scar contracture: call for a functional approach. *Wetenschappelijk overleg Vereniging Samenwerkende Brandwondencentra in Nederland (VSBN)*, 2017 [Rotterdam, The Netherlands]

Rating scales for scar contracture: call for a functional approach. *17th European Burn Association (EBA) congress*, 2017 [Barcelona, Spain] (presented by M.K. Nieuwenhuis)

Comparison of shoulder and elbow range of motion rating scales. *ScarCon ETRS*, 2018 [Amsterdam, The Netherlands]

Burn scar contractures that limit ADL functioning in children and adolescents: A preliminary longitudinal study. *Wetenschappelijk overleg Vereniging Samenwerkende Brandwondencentra in Nederland (VSBN)*, 2019 [Wijk aan Zee, The Netherlands]

Burn scar contractures that limit daily functioning in children and adolescents: A longitudinal study. *18th European Burn Association (EBA) congress*, 2019 [Helsinki, Finland]

From range of motion to function. Loss of joint flexibility after burns: when is it a problem? *Nederlandse jubileumcongres Fysiotherapie Groningen*, 2020 [Groningen, The Netherlands]

Poster presentations

Scar contractures after burn injury: a functional approach? *Master afstudeerproject voor de opleiding Human Movement Sciences Groningen*, 2013 [Groningen, The Netherlands]

Required shoulder and elbow joint angles in daily living tasks: an overview. *16th European Burns Association (EBA) congress*, 2015 [Hannover, Germany]

Why an operationalization of flexibility problems after scars in terms of function is needed. *ScarCon ETRS*, 2018 [Amsterdam, The Netherlands]

OTHER

'De opleiding fysiotherapie en onderzoek doen gaan uitstekend samen'. *Ervaringen studenten fysiotherapie op de Hanzehogeschool Groningen*. 2015.
https://www.hanze.nl/nld/onderwijs/gezondheid/academie-voor-gezondheidsstudies/opleidingen/ bachelor/fysiotherapie/organisatie/overzichten/testimonial/anouk-oosterwijk

Video: 'Onderzoek naar bewegingsbeperkingen bij brandwonden'. *Onderzoek uitgelegd, Lectoraat Healthy Ageing, Allied Health Care and Nursing*. 2018.
https://vimeo.com/271823130

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